COMMON COMMODITIES AND INDUSTRIES

INTERNAL COMBUSTION ENGINES

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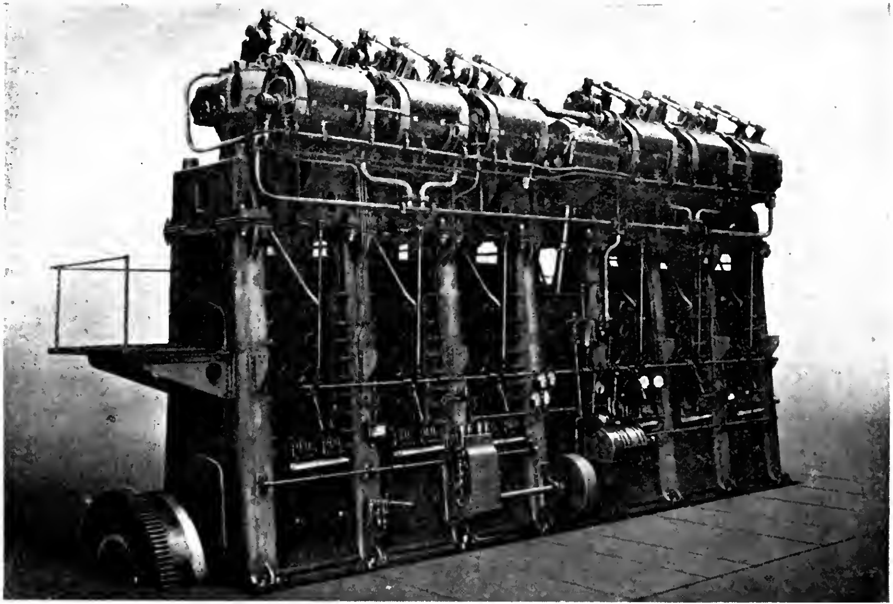
INTERNAL-COMBUSTION ENGINES



Vickers, Ltd. *Frontispiece*

1,250 B.H.P. VICKERS' " SOLID INJECTION " HEAVY OIL MARINE ENGINE

PITMAN'S COMMON COMMODITIES AND INDUSTRIES

INTERNAL-COMBUSTION ENGINES

A REVIEW OF THE DEVELOPMENT AND CONSTRUCTION OF VARIOUS TYPES AND THEIR ECONOMIC SUPERIORITY FOR MODERN POWER PURPOSES

BY

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PREFACE

The gradual substitution of mechanical power for all forms of manual labour formerly so common in manufacturing and agricultural trades, combined with the shorter working periods in all trades and professions, a world shortage of coal and oil, the huge development of mechanical transport and an increasing population throughout the world, are some of the reasons why the economical production of power is one of the most important of the many industrial problems now awaiting satisfactory solution.

The ever-increasing use of electricity, both for lighting and for power purposes, calls for the adoption of engines having the highest fuel economy. Power is required for the building and propulsion of ships and transport vehicles of all kinds, the amount of fuel used in their production is of course inconsiderable compared with that required to propel them during their life.

While steam power has fulfilled its purpose satisfactorily enough in the past, it has few applications at present where it is not challenged by the internal-combustion engine, owing primarily to the greater fuel economy of the latter.

The disadvantages of steam power plants comprise fuel inefficiency, and the large space occupied by boilers, water tanks, condensers, and other auxiliaries. Large bunker space is required, and expensive chimneys. Boilers require constant stoking, cleaning, and overhauling, bunkers require refilling, and this work, especially in marine installations, occupies a lot of time ; is very dirty, and necessitates the employment of a large

staff, the work being anything but congenial. Another feature against steam power is the necessary delay involved in the process of raising steam even on small plants.

Internal-combustion engines of the best type are largely free from the disadvantages mentioned, and it is the object of this book to show how gas and oil engines stand as competitors to steam for all power purposes, and to discuss some of the power requirements, the fulfilment of which is beyond the scope of the steam engine.

For assistance in enabling him to do this, the author expresses his thanks to those firms who have placed illustrations and particulars at his disposal.

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CHAPTER I

DEVELOPMENT OF THE GAS ENGINE

THE first law of thermodynamics tells us that when heat is completely transformed into work, the quantity of work is equivalent to the quantity of heat. The means, however, by which this conversion is carried out in practice are imperfect in varying degree, depending on the form of heat engine adopted to convert the heat energy of a fuel into useful work which may be taken from a revolving shaft.

Now as a prime mover is essential to almost every trade, and as modern power plants fall short of the ideal in converting heat into work, it is natural that in these days of keen competition in business, the development of efficient engines should attract an increasing amount of attention.

The science and practice of heat engines and mechanical engineering throughout the world is indebted to James Watt and Joseph Whitworth, men whose scientific and practical attainments were unique, and whose names are continually before us in class room and workshop at the present day.

To James Watt, for his practical application of the then little understood laws of heat, culminating in his invention of the rotative steam engine, and for many

ingenious devices still in use on present day engines, and to Joseph Whitworth for his skill in producing the first true surface plates, standard measure bars, and accurate measuring machines, and for standardizing. screw threads. Joseph Whitworth placed workshop processes on a scientific basis, and modern machine shop methods all over the world are a direct result of his pioneer work.

In 1769 Watt patented, and later constructed, the first steam engine using steam pressure on one side of a piston, exhaust steam from the other side being discharged into a condenser in which a vacuum was maintained. In 1784 the engine was made double-acting, the reciprocating motion of the piston was, through the medium of his famous parallel motion, converted into rotary motion at a crank-shaft, and thus came into existence the first rotative steam engine, and one which was much more economical in the use of steam than the atmospheric engines of the period. In the Newcomen engine, famous as the one which led Watt to his great discovery, steam was admitted to one side of a piston and condensed by a spray of water injected into the cylinder at the end of the stroke. A partial vacuum was thus created, and the pressure of the atmosphere, acting on the opposite side, forced the piston down on the power stroke. This was obviously a very wasteful method of using steam, and as the motion of the piston was not utilized to rotate a shaft, the engine could only be used for pumping purposes.

Since Watt's time improvements in the reciprocating steam engine have been in its mechanical features of construction rather than in principles of operation.

That Watt was handicapped by the lack of suitable materials and accurate machine tools is evidenced by his complaints, especially during the early stages of his

work, of the poor material and workmanship that he had to make use of, although this was the best obtainable at that time.

Slide-rest lathes, planing and boring machines, were unknown, and in order to overcome the difficulty of guiding the piston rod in a straight line he devised the parallel motion which obviated the use of slide bars. This did not get over the difficulty of the moving piston in the cylinder, and in an endeavour to make the piston of one of his engines tolerably steam-tight, he mentions having to wrap it round with cork, oiled rags, tow, old hat, paper, and other likely and unlikely materials. It is of interest to note that the pressure of steam that could be carried in the boilers at that time was not more than about 15 lb. per sq. in.

When tracing the history of the internal-combustion engine, one realizes how impossible it is to give credit to one man as being the original inventor in the true sense.

This statement is common to the history of most inventions, but seems especially so with respect to the internal-combustion engine.

So many have made suggestions and carried out experiments, that fresh minds entering the field of investigation at a later date have been able to make use of later discoveries in materials, of construction, and more perfect mechanical appliances in the way of machine tools, and so carry to a successful issue the suggestions and experiments of their predecessors.

Although experiments with gas engines have been carried out practically continuously since the time of Watt, it will be recognized that, as pressures and temperatures due to the combustion of gas mixtures in a cylinder are higher than with steam, and the temperature differences greater, the lack of suitable iron and steel combined with imperfect mechanical appliances

for the fashioning of parts must have considerably retarded development. For example, an aeroplane engine which is an unique example of modern design and accurate machine tool work, and which develops more horse power per pound of metal used in its construction than any other engine, operates on a cycle almost exactly as defined by Beau-de-Rochas in 1862. It is, however, constructed of materials the majority of which were unknown at that time.

The occasion of the centenary of James Watt, 1736-1819, was a fitting time to draw attention to the problem of fuel economy, and it is intended that an international memorial to commemorate the centenary shall take the form of a professorship of engineering at the University of Birmingham, to be known as the James Watt chair. The object of the chair is to promote research in "The fundamental principles underlying the production of power, and the study of the conservation of the natural sources of energy." In addition, it is proposed to erect a James Watt memorial building, to serve as a museum for collecting together examples of the work of Watt and his contemporaries, Boulton and Murdoch, to illustrate this interesting epoch in the history of engineering. Mathew Boulton, Watt's friend and partner for a period of thirty-five years, was a man to whom Watt owed much of his success, while William Murdoch, who from beginning work as a mechanic at the Soho works of Boulton and Watt at Birmingham, ultimately by reason of his mechanical skill and inventive genius became Watt's right-hand man and the guiding hand of the firm in all their important undertakings.

To Murdoch is due the invention of gas making, the first large plant to his designs being constructed and erected at the Soho works in 1802 for illuminating purposes.

There is no evidence that Murdoch ever had in mind the construction of a gas engine, the demand for his apparatus for generating coal gas for use as an illuminant, together with his responsibilities and interest in the steam engine, would no doubt keep him fully occupied.

As soon as gas became available for illuminating purposes, it was natural that attention should be directed to the possibility of using it for power purposes, and about 1825 experiments were commenced and carried on with great vigour in the endeavour to produce a satisfactory gas engine.

It is interesting to note that many of the early gas engines, like the Newcomen engine using steam, made use of gas by burning, expanding, and cooling it on one side of a piston so as to form a partial vacuum, the pressure of the atmosphere acting on the other side to give the return stroke, and this was the power stroke. Although not the first atmospheric gas engine to be constructed, the Otto and Langen (free piston engine) was one of the first gas engines to be placed on the market and to attain a considerable measure of success.

One of these engines was exhibited at the Paris Exhibition of 1867, and in 1875 Mr. Francis W. Crossley read a paper describing it before the Institution of Mechanical Engineers.

In this engine, a mixture of gas and air is drawn into the cylinder during about one-eleventh of the upward stroke of the piston, and is then ignited by communication with a gas flame through a port in the slide valve ; the piston is then forced upwards. As the motion of the piston is unretarded except by its own friction, owing to its inertia, it rises to a height which creates a pressure underneath it less than that of the atmosphere. This pressure is further reduced by the cooling action of the walls, so that the pressure of the atmosphere acting on

the opposite side of the piston, forces it down. As on the down stroke the piston rod rack, gear wheel, and main shaft are connected together, the down stroke is the power stroke.

Manufacture of the Otto and Langen engine was discontinued on account of mechanical difficulties of operation, it was of large size for the power developed, and was not of a suitable design for powers above 3 b.h.p. In addition it was unsteady and noisy in action. The gas consumption was reasonably low, some trials made by M. Tresca at Paris showed, for an engine cylinder $8\frac{3}{4}$ in. diameter by 3 ft. $5\frac{3}{8}$ in. stroke, a gas consumption of 44·7 cub. ft. per b.h.p. per hour. Dugald Clerk tested a 2 h.p. Otto and Langen engine using Oldham gas, the consumption being 36 cub. ft. per b.h.p. per hour.

Assuming gas of the period to have a calorific value of 650 British Thermal Units per cub. ft., the engine thus utilized some 10 per cent of the total energy in the fuel supplied to it, whereas a modern gas engine, on town gas, will convert 25 per cent to 30 per cent of the heat energy supplied to it into useful work at the crank shaft. As the price of town gas is approximately the same to-day as it was in 1875, and as the calorific value of modern gas is considerably less than at that date, the extended use of town gas for power purposes would seem to depend on the ability of the internal-combustion engineer to construct engines of still higher fuel economy.

The Otto and Langen and the Lenoir were the two best known engines obtainable in this country prior to the introduction of the Otto compression engine in 1875.

The Lenoir engine was invented in 1860, and although working on a cycle inferior to the Otto and Langen, it was much more silent in action, gave a more even

turning moment, and was ahead of others in that it used electric ignition, sparking plugs being fitted as in modern petrol engines.

Lenoir aspired to build a gas engine on the lines of a steam engine, that is pressure was applied alternately to both sides of the piston, the engine thus being double acting as in present day steam engine practice. This feature of gas engine construction is not yet universally adopted except for engines of high horse-power.

The early Lenoir engine was of the non-compression type ; on the outstroke of the piston gas and air entered the cylinder until about half stroke was reached, and the mixture was then ignited by electric spark. On ignition, the pressure rose to about 65 lb. per sq. in., thus forcing the piston out for the remainder of its stroke. The waste gases were expelled to the atmosphere during the return stroke, a new charge of gas and air entering the opposite end of the cylinder, the operation of ignition and exhaust following. The gas consumption of the Lenoir engine was approximately 100 cub. ft. per b.h.p. hour, thus showing that less than 4 per cent of the fuel energy was utilized as useful work. This engine was also of large size for the power it developed and as may be imagined from its low fuel efficiency and the fact that it was double acting, it rapidly overheated and had to be stopped.

CHAPTER II

THE MODERN GAS ENGINE

THE patent specification lodged in Paris in 1862 by Beau-de-Rochas defines clearly and with prophetic accuracy the cycle of operations on which modern gas engines operate.

The first engines to operate on this cycle were constructed by Otto in 1876. These engines were immediately successful, and to-day gas, oil, and petrol engines operating on the Otto cycle, as it is called, are constructed in great numbers all over the world.

In its modern form, the Otto cycle engine made of high-class materials machined to a fine degree of accuracy gives universal satisfaction.

As the Otto cycle is fundamental when following the development of internal-combustion engines, no apology is necessary for outlining the sequence of events in a four-stroke single-acting Crossley gas engine—

(1) **The Charging or Suction Stroke.** The piston moves out, the mixture valve opens and at the end of this stroke the cylinder is filled with an explosive mixture at approximately atmospheric pressure.

(2) **The Compression Stroke.** The piston now moves in, the inlet valve is closed and the mixture compressed to a pressure when using town's gas of, say, 80 to 100 lb. per sq. in. by gauge. At the end of this stroke the combustible particles are brought into more intimate contact with each other, the volume they occupy is now about one-fifth of what it was at the end of the charging or suction stroke. Also, the enclosing surface is of much smaller area than at the end of the charging

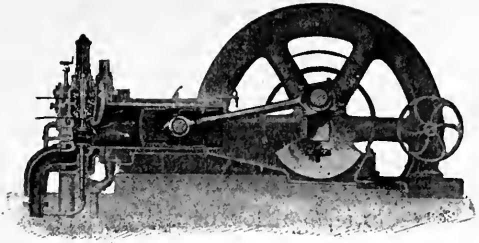


Fig. 1

THE SUCTION STROKE

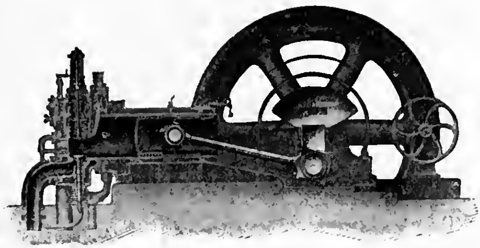


Fig. 2

THE COMPRESSION STROKE

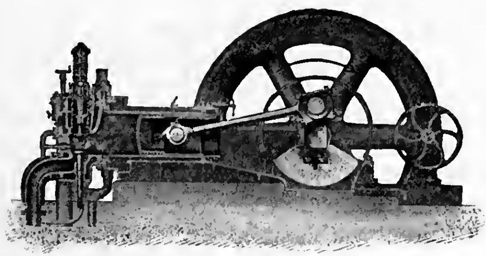


Fig. 3

THE POWER STROKE

stroke, thus the conditions in the cylinder are favourable for rapid and efficient combustion of the charge, with the minimum of heat loss to the cylinder walls, cover, and piston head, when ignition takes place.

(3) **The Power Stroke.** Just before the commencement of this stroke, ignition of the compressed charge has started and is timed to be complete just after the power stroke has commenced. On ignition, the pressure rises almost instantly to three or four times that of compression, and the piston is forced outwards, the pressure falling as the gas expands during the stroke. As the piston moves out on the power stroke, heat is given to the cooling water in the jacket surrounding the cylinder. This is a source of heat loss, nevertheless the water-jacket is a necessary feature.

(4) **The Exhaust Stroke.** Towards the end of the power stroke the exhaust valve opens, the expanded gases escape into a silencer and from this to the atmosphere. The exhaust gases, escaping at a low pressure and fairly high temperature, also carry away a large percentage of the heat in the fuel. Owing to their low pressure, the exhaust gases are of no further use on a piston.

All gas and petrol engines, and some few oil engines using refined paraffin, operate on the Otto cycle as outlined, but it must be understood that with this cycle the combustible mixture is always in the cylinder during the whole compression stroke. A single-acting four-stroke engine of this type gives one power stroke for two revolutions of the crank shaft.

Thus there are engines which operate on the two-stroke cycle, the combustible mixture being in the cylinder during the whole of the compression stroke. A single acting engine of this type gives one power stroke for each revolution of the crank-shaft and may be termed a

two-stroke Otto engine as distinguished from two-stroke Diesel or semi-Diesel engines, because in these latter air only is in the cylinder during the compression stroke.

The simplest form of two-stroke single-acting engine, usually a petrol engine, is in a sense valveless, the main piston serving a dual purpose by also acting as a valve, covering and uncovering inlet and exhaust ports cut on opposite sides and at the crank end of the cylinder.

The operation of such an engine is simple. Imagine the piston to be at the inner end of its compression

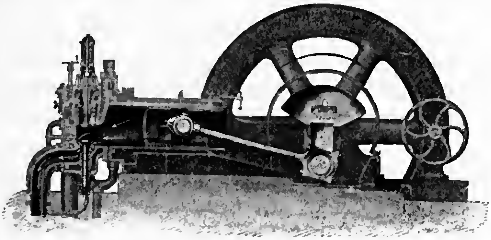


FIG. 4

THE EXHAUST STROKE

stroke ; on ignition of the compressed charge behind it the piston is forced outwards by the pressure of combustion, which may be three or four times that of compression ; this constitutes the power stroke. When the piston has travelled about three-quarters of its power stroke, it uncovers slots or ports cut in the cylinder wall and the spent gases escape through a silencer to the atmosphere. When the piston has completed about seven-eighths of the same stroke it uncovers other slots cut in the opposite side of the cylinder wall ; these are the inlet ports through which the gas mixture is forced into the cylinder by suitable means under slight external pressure. Both inlet and exhaust ports remain open

until the piston covers them during the first portion of its return or compression stroke. The cycle of operations is then repeated.

The thermal or fuel efficiency of an engine depends on the pressure to which the combustible mixture in the cylinder is compressed when ignition occurs. With gas engines using town gas a satisfactory pressure is 80 to 100 lb. per sq. in. If the compression pressure is much above 100 lb. per sq. in. combustion is very rapid, and, further, pre-ignition is likely to occur owing to overheating, the temperature attained too early in the compression stroke coinciding with the spontaneous ignition temperature of the gas mixture. In his patent specification, Beau-de-Rochas stated that the mixture was to be compressed to such a pressure that the resulting temperature would be high enough to ignite the charge without the aid of any other ignition device. Thus Beau-de-Rochas not only gave to the world the present gas engine cycle, but also indicated the manner in which an engine could be made self-igniting and a simple modification of his suggestion is a feature of present day heavy oil engines.

If this feature of self-ignition by compression could be adopted in gas engines, one of the troublesome features of operation would be eliminated. Unfortunately, owing to variations in cylinder temperature, due to variations in load and quality and quantity of gas mixture, ignition by compression is not a practical proposition with the present form of gas engine.

With modern compression pressures, the fuel efficiency referred to the shaft horse-power is from 25 per cent to 30 per cent at full load, or reckoned with respect to the work done on the piston, say, 33 per cent, corresponding to a mechanical efficiency of nearly 90 per cent as regards the working parts of the engine itself.

Further increase in the fuel economy of gas engines would seem to depend on the adoption of a cycle that does not involve the presence of the combustible mixture in the working cylinder during the compression stroke.

For engines up to, say, 20 b.h.p. town's gas is probably as cheap, all things considered, as gas generated from a small gas producer.

An engine using town's gas requires practically no attention after starting up, whereas a producer gas plant does require more, the engine and producer for even small powers requiring such attention as to interfere with an attendant from doing other really useful work. For intermittent work or in special cases, it may pay to run higher powered engines on town's gas, but this depends on circumstances. As a general rule it is more economical and convenient to arrange for a supply of both town's and producer gas to all engines up to approximately 100 b.h.p.

An engine running on town's gas will consume at full load 20 to 25 cub. ft. of gas (calorific value 500 B.Th.U. per cub. ft.) per brake horse-power per hour, whereas an engine supplied with gas from a suction type gas producer will burn about 1 lb. of anthracite per b.h.p. per hour.

Assuming gas at 4s. per 1,000 cub. ft. and coal at 60s. per ton, the cost for fuel only when running on town's gas works out to be $1\frac{1}{5}$d., and for the producer gas engine practically one-third of a penny per b.h.p. per hour.

The cost of running a 20 b.h.p.[1] engine for a 48-hour week would thus be £4 16s. on town's gas, and £1 6s. on producer gas, a saving, neglecting stand by losses, of approximately £3 10s. per week on fuel.

[1] See page 43.

Against this must be put the cost and depreciation of the gas-producer plant, attendant's wages and considerations of accommodation, coal storage, transit, etc. Single cylinder horizontal gas engines up to 150 b.h.p. are highly satisfactory for all classes of work hitherto done by steam and, being close governed and fitted with a suitable fly-wheel, give a remarkably steady drive even when direct-coupled to a dynamo used for electric lighting.

CHAPTER III

SPEED CONTROL AND IGNITION SYSTEMS

Speed Control Devices. Single cylinder, single-acting four-stroke engines have only one power stroke in four. As a consequence a fly-wheel of suitable mass and rim speed has to be fitted.

The fly-wheel must be capable of storing sufficient energy during the power stroke, to prevent great fluctuations of speed during the other strokes of the cycle.

Increasing the number of power strokes, by increasing the number of cylinders and cranks, enables the fly-wheel capacity to be reduced ; but even with multi-cylinder engines a good fly-wheel adds to the steadiness of running by preventing sudden changes in angular velocity of the crank-shaft and consequent jerky action of the governor.

Stationary engines are usually required to run at a constant speed under all conditions of load, and to enable them to do this an automatic governing device is necessary.

Governing devices regulate the quantity of gas or oil supplied to an engine cylinder to suit the load under which it is working ; thus they form a very important detail part of any engine. Three principal systems of governing are adopted. These comprise, " hit and miss," quality, and quantity. Sometimes a fourth system is used, this being a combination of any two of the systems mentioned.

With the " hit and miss " system, the action is as follows : When running under a light and steady load,

the gas valve is cut out of action by the governor at regular intervals for periods extending over a number of cycles, and so the speed is maintained fairly constant.

When the load is reduced the speed increases slightly, the governor then prevents the gas valve from opening until the speed is again normal. When the load is increased, the speed falls slightly; the governor now causes the gas valve to open for consecutive cycles until normal speed is again reached.

During cut-out strokes, air only is taken into the cylinder. As a result of the scavenging effect of this air, the next charge taken in is undiluted by any exhaust gas from the clearance spaces, and the work done during the stroke is consequently above the average. This system of governing is very economical; as the gas taken in is always subjected to full compression it gives out the maximum amount of work.

During cut-out strokes the air supply to the cylinder is not restricted and so the pressure behind the piston is practically atmospheric.

Owing to the intermittent occurrence of power strokes, the "hit and miss" system does not give as steady running as the other systems. It is not generally adopted on engines above 100 b.h.p. per cylinder, owing to the high stresses imposed on the heavy moving masses when ignition occurs immediately after a cut-out stroke.

Engines governed on the "hit and miss" system should not be so heavily loaded that no cut-out stroke occurs; if this does happen the engine is liable to pull up.

With quality governing, the governor operates to reduce the proportion of gas or oil supplied to the cylinder; the air supply is, however, not reduced. The main advantage of the quality system is that the mixture is always compressed to the full compression

pressure and is ignited in regular sequence. At low loads ignition of the charge is apt to be somewhat uncertain, but as variable ignition timing is usually fitted to gas engines this feature is not troublesome.

A quantity governor varies the quantity of combustible mixture admitted to the cylinder (during the suction stroke) to suit the load against which the engine is working. By reducing the quantity of gas and air, the pressure to which it is compressed is less than when a full and unrestricted charge is admitted ; but as the proportion of gas to air remains constant the ignition is good at low loads and the power strokes occur in regular sequence.

Owing to the low compression pressures at light loads the thermal efficiency is less than at full load, nevertheless quantity governing is the system in most general use.

Electric Ignition Systems. In Otto cycle engines the charge is now almost universally ignited by electric spark. Two main systems are in use, termed respectively high and low tension. The source of electric current may be magneto-machine, dynamo, electric light mains, accumulator or dry battery, according to the ideas of the engine designer and user and to suit the special purpose for which the engine is to be used.

For ordinary gas engine ignition purposes a low-tension magneto is generally used. This consists of a simple H armature oscillating between the poles of a permanent magnet.

One end of the armature winding is "earthed" to the frame of the machine, while the other end is suitably led to the insulated pole of an ignition plug which is screwed into the combustion chamber of the engine ; the poles of the plug are short circuited except when a spark is required. The armature only moves through part of a revolution, and this part includes a maximum

current position. Just before an ignition spark is required, a trip gear, mounted on the cam shaft, turns the armature through an angle of about 30°. As the armature normally stands in a maximum position and is held there by strong springs attached to an arm on its shaft, the angular displacement will bring it to one side of its maximum position. At the required time, the trip gear releases the armature which is sharply rotated under the action of the springs. When it is passing through its maximum position the two poles of the ignition plug are quickly separated by mechanism operated from the armature shaft. At this instant, a flaming spark of great intensity passes across the igniter contacts in the cylinder and so fires the charge.

The low-tension system is used only on engines of moderate power and comparatively low speed. At high speed the features against it are the inertia effects of the operating mechanism and the hammer-blow action of its various parts. Further, with large cylinders, owing to the greater volume of gas to be ignited, two or more ignition plugs are fitted to each cylinder to insure efficient inflammation of the mixture. With the system just outlined, this necessitates a separate magneto for each ignition plug.

On large slow-speed gas engines, fitted with low tension ignition, the make and break device in the cylinder is operated magnetically by current from the main supply. This arrangement simplifies multi-plug ignition.

By using one or more low-tension magnetos, the armatures of which are rotated by toothed gearing from the engine shaft, and transforming the low-tension into high-tension current by passing it through an induction coil, the high-tension current may be led by cables from the coil terminals to the insulated poles of the

several fixed point sparking plugs. In this case the armature circuit is interrupted by a self-contained contact breaker.

The foregoing is an example of high-tension ignition, the voltage generated, i.e. 2,000 to 5,000 being high enough to cause the spark to jump the narrow gap between the plug points in the combustion chamber.

Although the principle on which high-tension spark plugs are constructed for gas engines is the same as that common to motor car engine plugs, the gas engine plugs are of much more robust construction.

In the large engines built by Galloways, Ltd., each cylinder is provided with three ignition plugs of the low tension make and break type. The low-tension current is supplied at a pressure of 65-70 volts. There is a distributing commutator on the end of the counter-shaft, by which, at the appropriate moment, the circuit is completed through a solenoid, the plunger of which, in moving, strikes a lever attached to the rotating spindle of the ignition plug and so breaks the circuit at the plug points, thus causing the spark to pass. The moment of ignition and (in the case of blowing engines) the duration of the contact of the brushes on the commutator segments are capable of independent adjustment. A visible indication of the correct functioning of the ignition plugs is given by means of glow lamps, mounted on a switchboard on the side of the engine.

For motor car, cycle, and aero engines, and all high speed petrol engines, the self-contained high-tension magneto ignition system is in universal use.

The armature of the high-tension magneto carries a primary and a secondary or high-tension winding, a contact breaker for the low-tension circuit being fixed to the armature shaft.

When the primary circuit is interrupted by the contact

breaker, a high-tension current is generated in the secondary winding, and as this current is at sufficient pressure to jump the air gap between the fixed points of the spark plug, the resulting sparks ignite the compressed mixture in the engine cylinder.

Magnetos are usually of the two-spark type, that is for each complete revolution of the armature two separate ignition sparks are available.

In the case of magnetos for firing engines having more than two cylinders, the high-tension current is collected by a fixed carbon brush, held in contact with an insulated brass ring to which one end of the secondary winding is connected.

This brass collector ring is mounted on and rotates with the armature shaft, and from the collector brush the current is led to a rotating carbon distributor brush, the speed of rotation of which is regulated by gearing, and is always one-half that of the crank shaft. The rotating distributor brush comes into rubbing contact with brass strips, these are insulated from each other by being recessed into a stationary block of insulating material. From the strips well insulated wires conduct the current to the insulated poles of the respective spark plugs.

As the armature of a magneto has only two spark positions per revolution, it is driven at different speeds according to the number of cylinders to be fixed. Thus in a four-cylinder four-stroke petrol engine the cranks are all in the same plane, and as there are four cylinders, there will be four power strokes for two revolutions of the crank-shaft.

The magneto armature must therefore rotate at the same speed as the crank-shaft, and the distributor brush at half the crank-shaft speed, the insulated brass strips being spaced at 90° from each other.

CHAPTER IV

LARGE GAS ENGINES

Although the internal-combustion engine is the most efficient prime mover ; even in the best type of engine a large proportion of the energy supplied to the cylinder as fuel must be conducted away through the cylinder cover and walls in the form of heat, while almost the same proportion escapes in the products of combustion passing through the exhaust valve to the atmosphere.

Horizontal four-stroke engines developing up to 150 b.h.p. maximum per cylinder can be obtained with water-cooled cylinders only, but some makers prefer to water-cool in addition the piston and exhaust valve of engines developing above 130 b.h.p. per cylinder.

The reason for these extra cooling arrangements is that the cooling surface of the cylinder of an engine does not increase in proportion to the volume enclosed ; hence, in order to maintain a sufficiently low cylinder temperature, in the case of larger cylinders the piston and exhaust valve are water-cooled in addition to the cylinder head and barrel.

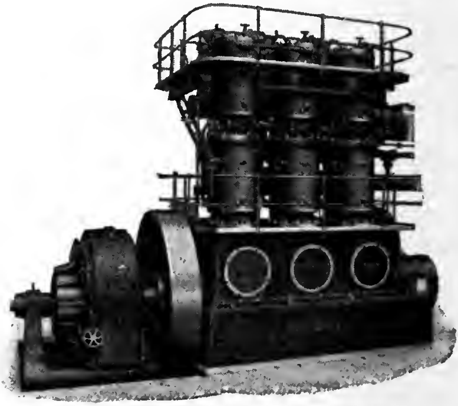
The necessity for efficient cooling is greater with two-stroke and double-acting engines, owing to the greater number of heat units to be transmitted through the enclosing surfaces.

Gas engines of the horizontal type are in most universal use, but in recent years considerable development has taken place in the construction of multi-cylinder multi-crank vertical engines having two cylinders (arranged tandem) per crank. The National Gas

Engine Co., Ltd., have specialized in this latter type and build engines in sizes from 300 to 1,500 b.h.p.

Multi-cylinder vertical engines, having one single-acting cylinder to each crank, have, of course, been a standard production for a number of years.

Vertical engines require the minimum of floor space; with the tandem type each crank receives an



National Gas Engine Co., Ltd.

FIG. 5

VERTICAL TANDEM GAS ENGINES
300 to 1,500 B.H.P.

impulse every revolution, thus an exceptionally even turning moment is obtained with a good mechanical balance of the reciprocating parts.

By multiplying the cylinders in this way, high-powered engines can be produced without the necessity of water-cooling any of the moving parts.

Obviously, increasing the number of cylinders also increases the number of working parts, but the result

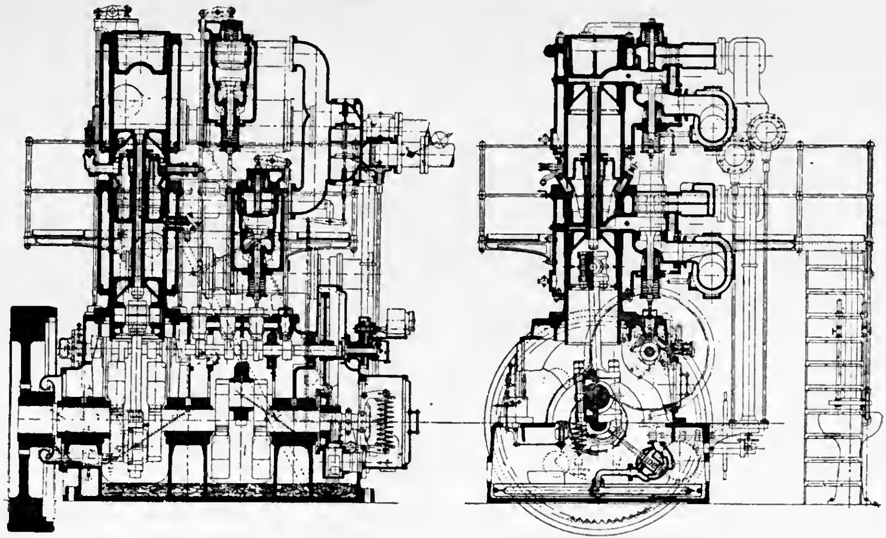


Fig. 6

SECTION THROUGH TANDEM GAS ENGINE

is an engine that gives a very uniform turning moment; the stresses in the working parts are low as also are the bearing pressures.

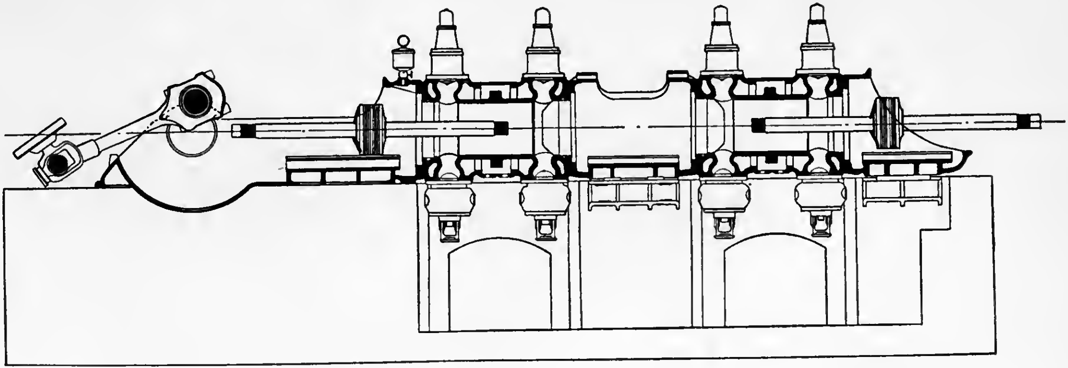
As an example of unique design in vertical engines, it is interesting to note that the Premier Gas Engine Co. build a single-crank, four-cylinder, double-acting engine, operating on the four-stroke cycle and developing 1,000 b.h.p. at 125 r.p.m. In this engine the pistons are water-cooled.

For high-powered engines of the horizontal type, the Otto or four-stroke cycle is adopted, with two double-acting cylinders, arranged tandem fashion, to each crank. This gives an impulse each stroke as in a double-acting steam engine, to which, for smoothness of running it is not inferior.

Large horizontal gas engines are built with cylinders up to 55 in. diameter. Fitted with a crosshead, the cylinder parts are efficiently lubricated and the pistons and gudgeon pins work under the best conditions ; all parts are easily accessible for overhaul or adjustment when this is necessary, although the engines run continuously for periods of six months without stopping for attention of any kind. Messrs. Galloway's, Ltd., build tandem-cylinder single-crank engines of this type up to 3,000 h.p.

In order to increase the power output per cylinder, horizontal, double-acting engines are also built to operate on the two-stroke cycle.

The two-stroke double-acting gas engine is a modification of the idea first worked out by Sir Dugald Clerk in 1877. In its modern form, known as the Korting double-acting two-stroke engine, it claims to develop nearly four times the power per cylinder, of the same bore and piston speed, as does a four-stroke single-acting engine.



Galloways, Ltd.

Fig. 7

METHOD OF REMOVING PISTONS AND RODS OF A LARGE GAS ENGINE

In the Korting engine the piston is of a length equal to its stroke, the cylinder being double the length of the piston stroke, plus a combustion chamber at each end into which opens a gas mixture valve.

Exhaust ports are cut round the inner circumference at the centre of the cylinder. Separate gas and air pumps are driven from the main crank-shaft of the engine, these pumps discharging through the respective inlet valves into the combustion chambers.

Briefly the action is as follows—

When the piston is at the end of its stroke, the exhaust ports are uncovered, thus allowing the exhaust gases to escape to the atmosphere. While the exhaust ports are still open, and as soon as the pressure in the cylinder falls low enough, the inlet valve opens and air is first discharged into the cylinder, sweeping before it the exhaust gases remaining, and so scavenging the cylinder.

Immediately following the admission of air, the gas pump discharges its contents into the cylinder, The gas, mixing with the air already there, thus forms the combustible mixture.

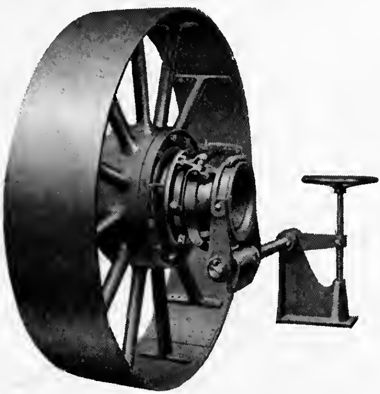
The return stroke is the compression stroke, at the end of which ignition occurs, and the power stroke follows for this end of the cylinder. As the action as regards the other end of the cylinder is exactly repeated; in this type of engine there are two power strokes for each revolution of the crank-shaft.

While internal-combustion engines may, generally speaking, be started up in less time than is necessary to start a steam engine, they cannot be started against heavy loads. In order to render them suitable for the special applications for which steam engines with their low starting speed and enormous starting torque are peculiarly adapted, in some cases a clutch is interposed

between the engine shaft and the shaft of the machine to be driven.

Such clutches are necessarily of the slipping type, after the style of a motor car clutch in which the power is transmitted from one shaft to the other through friction surfaces.

When the engine has got well into speed the clutch



British Hele-Shaw Clutch Co., Ltd.

FIG. 8

FRICTION CLUTCH PULLEY FOR A LARGE GAS ENGINE

is gradually engaged, and the load is picked up without shock and without stalling the engine.

An excellent form of clutch is the Hele-Shaw fluid pressure transmission type, in which a series of cylinders fitted with plungers are arranged radially in a circular casing. If the plungers are reciprocated by the driving shaft and the cylinders are attached to the driven shaft, or *vice versa*, then by regulating the resistance to the flow of fluid (oil), displaced by the plungers in a closed

system, the driven shaft is caused to rotate at a speed which may be gradually increased from zero up to the same speed as the driving shaft.

An additional advantage of a clutch is that on occasion the driven machine may be instantly disconnected from the engine and quickly brought to rest. A slipping clutch is also necessary in applications where a machine is required to be started very slowly into motion, and run at a slow speed for short periods.

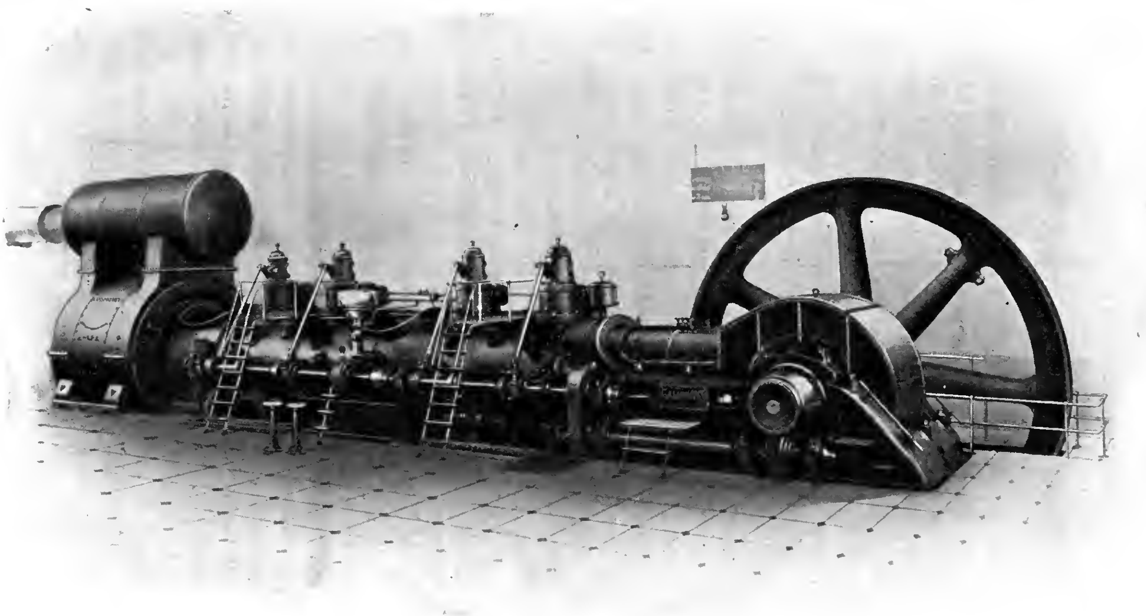
Gas and oil engines up to about 30 b.h.p. are readily started against no load by the combined efforts of two or three men pulling on the rim of the fly-wheel.

High-powered engines are usually started by compressed air. This is admitted to the engine cylinders from storage reservoirs, which are kept charged at a pressure of approximately 250 lb. per sq. in. by an independently driven air compressor.

Many large gas engines are coupled to electric generators, the power from these being utilized for lighting purposes, or distributed to electric motors which in turn drive the various machines in factory or workshop. Engines using blast furnace gas are usually coupled direct to the air compressors supplying air to the blast furnaces.

In such applications, when starting up, valves on the air compressor cylinder are held open to the atmosphere, and this very considerably reduces the load on the engine.

Large gas engines have been developed largely due to the initiative of Mr. B. H. Thwaite, who in 1894, demonstrated the possibility of using the gases discharged from the blast furnaces used for the production of pig iron from its ores. Prior to this, blast furnace gas was used in stoves for heating the air blast going to the smelting furnaces, and for raising



Galloways, Ltd.

FIG. 9

GAS BLOWING ENGINE

steam to operate the blowers supplying air to the furnaces.

Mr. Thwaite proved that a much more efficient method of using the gas was to burn it in the cylinders of gas engines and to use these to drive the blowers supplying blast air, the surplus power being available for lighting and other purposes additional to the requirements of the plant from which the gas is generated.

As it leaves the furnace the gas contains a considerable quantity of abrasive dust, which is very injurious to the interior working parts of a gas engine. This dust is removed by suitable filtering apparatus, and the gas is cooled before entering the engine cylinder.

The calorific value of blast furnace gas is approximately 100 B.Th.U. per cub. ft., but as it contains only a small percentage of hydrogen, $1\frac{1}{2}$ to 3 per cent, its cylinder compression pressure may be reasonably high, 160 to 190 lb. per sq. in.

Coke oven gas, also used in large gas engines, is a by-product from the furnaces used to convert coal into metallurgical coke, this latter being mixed with the ore in blast furnaces.

Coke oven gas is of high but variable calorific value, 400 to 500 B.Th.U. per cub. ft. The percentage of hydrogen contained in it is high, hence the engine compression pressure is usually 100 to 120 lb. per sq. in. Like blast furnace gas, coke oven gas contains dust and matter in suspension injurious to the engine, in addition, as it is made from bituminous coal, tar is present and has to be removed as the gas leaves the producer and before it enters the pipe line.

A recent inquiry by the Board of Trade to determine the quantity of coke oven gas generated in the United Kingdom shows that something like 7,250,000,000 cub. ft. per annum is available for various industrial purposes.

As the gas is generally only slightly inferior in calorific value to town gas, some of this huge volume is already supplied to town gas undertakings which are suitably located to coke oven plants. A large quantity is, however, still available, and it is suggested that this might be used as a substitute for petrol on motor vehicles. In view of the comparatively recent experience with gas storage systems on motor vehicles, the suggestion is not very opportune.

Until a few years ago, the installation of large gas engines was not looked on with favour, and the behaviour of some early engines undoubtedly created prejudice against their use, which was certainly justified. It is to the credit of British builders, however, that the large gas engine is now increasing in popularity owing to its economical and reliable service.

Many power stations in which are installed gas engines developing 10,000 h.p. and upwards, are in successful operation in this country, and the results of extended observations and tests of such engines are frequently published in the technical press.

The Marine Gas Engine. While the gas engine is more popular for service on land than is the oil engine, the condition of things is reversed as regards its application to the propulsion of ships.

A few ships have from time to time been fitted with gas engines and producers for experimental purposes, but up to the present no useful progress has been made, and at the moment any possibilities the marine gas engine may have are completely overshadowed by the great success attained for this work by the oil engine.

The successful application of the producer gas engine to the propulsion of ships is a problem connected more with the producer than the engine. Producers occupy considerable space, and this must be well ventilated

so as to avoid the risk of carbon-monoxide poisoning, a danger which has always to be carefully guarded against, even with installations on land where space is not necessarily so restricted.

The problem of starting and reversing are similar with both gas and oil engines, but the gas engine, as a machine, and excluding the producer, is somewhat simpler than the oil engine. For the gas engine it may be said that coal fuel is a more stable product as regards price and supply than oil fuel, coal being, so to speak, a home grown if not a universal product.

CHAPTER V

CRUDE OIL, PETROL, AND BENZOL

Up to a certain point, reciprocating gas and oil engines have developed along parallel lines, but whereas the gas engine early reached a stage of development beyond which it does not seem likely to advance, at any rate for stationary power purposes, developments in connection with oil engines proceed apace.

Oil is energy in the most concentrated form available for safe and convenient storage and handling, and although of complex structure, its properties are well understood.

That familiarity with these properties give it a simplicity that is more apparent than real, is evidenced by the great variety of vaporizing and ignition systems now in use with oil engines.

The fuels used by oil engines, including petrol engines, are derived chiefly from crude petroleum, although many engines now successfully burn benzol, tar oil, or creosote oil, these being distilled from coal tar, itself a by-product from the carbonization of bituminous coal when used for gas making and in the manufacture of coke in coke ovens.

Crude petroleum as it comes from the earth comprises mixtures of hydrogen and carbon (hydro-carbons) varying from a gas to solid paraffin. When heated in retorts subjected to different temperatures, crude oil gives off vapours which, when condensed, yields the following—

Distillates below 300° Fah. Petroleum ether, rhigolene, gasolene, or petrol, etc., all these have flash points

below 73° Fah., that is, they give off vapour sufficiently freely below this temperature to form an ignitable mixture under atmospheric conditions.

Distillates above 300° Fah. Lamp oils and other high flash oils such as solar oil, lubricating oils, paraffin oils, from which wax is made, the residue, which is a sticky mass of pitch-like oil, being used for firing steam boilers, and as an asphaltic coating for roofs, etc.

In order to supply the demand for fuel oil, the distillation process may cease after the lamp oil series has been distilled off, the residue being used as fuel oil.

Some crude oils are particularly rich in light distillates, while others yield a very small percentage. Generally speaking, crudes having a specific gravity below ·85 yield a much higher percentage of volatiles than crudes having a specific gravity above this figure.

The name crude oil, although generally accepted as designating an oil actually obtainable for use with what are variously called crude or heavy oil engines, is somewhat of a misnomer.

Crude oil is not obtainable for use as a fuel exactly as it is taken from the well : before it becomes a commercial product the more volatile constituents are first distilled from it.

The most volatile fuels that are made use of in internal-combustion engines are petrol and benzol.

Benzol is a distillate of tar, this being a well-known product of the bituminous coal used in the manufacture of domestic gas. Tar is also obtained from power gas producers which use bituminous coal, as well as from coke-oven plants.

In recent years a further yield of benzol has been obtained by recovering it from the gas itself. This process, known as "stripping," consists of washing the gas with oil by passing it through a form of scrubber.

After passing through the scrubbing process the benzol is recovered from the washing oil by distillation.

Although benzol is quite as satisfactory a fuel as petrol, and is very popular so far as it can be obtained, it is not available in such large quantities as to render it a serious competitor to petrol.

The chief objection to the use of volatile fuels such as petrol and benzol, apart from their prohibitive cost when considered as fuels for general power purposes, is the danger of fire and explosion when they are used or stored in enclosed spaces, and when, as is always the case, they are carried on airships and aeroplanes.

Fires may be caused in many ways, and great care should be taken to prevent the accumulation of petrol vapour in confined places such as a garage, cellar, or the hull of a boat, due to leakage of petrol from faulty pipe fittings and tanks.

A fire may start through an inlet valve sticking open, or to a slow burning mixture existing in an engine cylinder during the suction stroke and on the opening of the valve firing back to the carburettor.

Extreme volatility is not usually a dangerous property attending the use of petrol on motor vehicles, but on launches and aircraft, from which there is no escape should a fire occur, the devastating effects of burning petrol demand that every encouragement should be given to investigators in their endeavours to use the less volatile fuels for this work.

The free vaporizing property of petrol and benzol has nothing to do with their ignition temperature. For example, a mixture of petrol vapour and oxygen, or air, actually requires to be heated to a higher temperature, called its spontaneous ignition temperature, to cause it to ignite, than does a mixture of paraffin oil or crude oil vapour.

These latter fuels vaporize so slowly at atmospheric temperature that with ordinary care in storing and handling, they are perfectly safe fuels.

The free vaporizing property of petrol and benzol renders them the easiest liquid fuels to use in internal-combustion engines.

These fuels vaporize freely under all atmospheric conditions, and when sprayed from a small jet tube or nozzle placed in a stream of air, the fine particles of liquid readily evaporate and form with the air a combustible mixture whose quality and quantity depends on the respective amounts of petrol and air brought into contact with each other.

CHAPTER VI

THE PETROL ENGINE

Since the introduction of the petrol engine by Daimler, in 1896, the unique features of this type of internal-combustion engine have made it indispensable for a variety of purposes.

Petrol engines enter so largely into the everyday life of everyone, that knowledge concerning its construction and operation is remarkably widespread among people who otherwise have very little technical knowledge.

The petrol engine has made road locomotion the great success it is to-day, because of the unique advantages it possesses over every other prime mover for the exacting requirements of road vehicle propulsion. It is of light and compact construction, and may be started up and put to work against full load in as short a time as an electric motor. Its reliability under all conditions of load and its ability to withstand rough treatment at the hands of unskilled drivers, place it in a position of undoubted security against all competitors for many years to come.

For the propulsion of aeroplanes and airships, at the moment it has no competitor, while for a multitude of other purposes where moderate power is required it is eminently satisfactory, and the more important of these will be dealt with.

For all purposes, petrol engines are of either the four or two-stroke type, and are always single-acting.

The four-stroke is most in favour for motor vehicles, the two-stroke being popular for motor boat propulsion and for light weight motor cycle work.

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In the four-stroke poppet valve engine, various arrangements of valves are adopted. In a T-headed engine, inlet and exhaust valves are placed on opposite sides of the cylinder; this necessitates two separate cam-shafts, and although the combustion chamber is not of the best form for high fuel efficiency, the engine is very accessible. Another, and the more usual arrangement, is to have all the valves on the same side, this gives what is called a L-headed engine.

Except that it is rather more difficult to construct, the most efficient type of engine is one in which the inlet and exhaust valves are located in the cylinder head, the cam-shaft being placed along the top of the cylinders, or the valves may be operated by levers and push-rods from a cam-shaft located in the crank case.

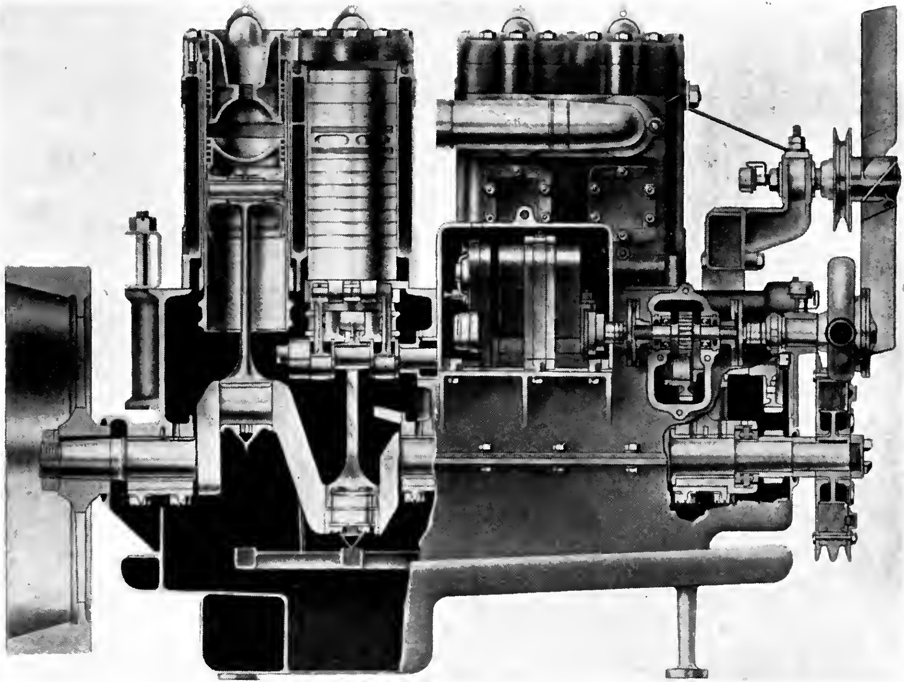
The overhead design presents some difficulty owing to the restricted space available for the valves and their seats. Detachable seats are necessary for valve re-grinding purposes.

With overhead valves the cylinder head is made conical to provide sufficient space for them; and when the top of the piston is dished the combination approximates to a spherical combustion chamber.

Cylinder heads may be detachable, but are usually cast solid with the piston barrel and water jacket metal. The detachable head has advantages and appears to be again coming into favour.

In any type of internal-combustion engine the ideal shape for the clearance space or combustion chamber is spherical; a sphere encloses the maximum volume with the minimum surface, the effect of minimum enclosing surface is to reduce heat loss from the gases during the combustion period, and so increase the fuel economy of the engine.

A sleeve-valve engine approximates to the ideal form



The Daimler Co., Ltd.

FIG. 10

SECTIONAL VIEW OF DAIMLER SLEEVE-VALVE ENGINE

of combustion chamber, at the same time enabling unrestricted port area for the flow of both inlet and exhaust gases.

The combustion chamber of a sleeve-valve engine is machined throughout, there being no rough surfaces to which soot may readily attach itself ; also, the clearance volume and compression space in each cylinder will be exactly equal, as also will be the resulting compression pressures. The sparking plug is well placed in the centre of the compression space, combustion will therefore be rapid and complete, with the minimum of heat loss to the cylinder surface at the instant of maximum pressure and temperature.

Sleeve valve engines are very quiet when running, the valves themselves require no attention in the way of grinding, and, considered as a radical departure from ordinary petrol engine design, it is a great success.

Almost any part of a poppet valve engine can be repaired or renewed by an ordinary mechanic, quite a number of the smaller parts for most of the well-known engines are obtainable at depots in the principal towns.

While petrol engines have attained to a remarkable state of reliability it is important to be able to effect a replacement should such become necessary. In the case of motor vehicle engines, the Ford service system is an example of efficiency in this respect.

To the ordinary observer who compares the large size and heavy construction of, say, a 20 h.p. stationary type of gas or heavy oil engine, or any low speed engine, with the compact and light construction of a petrol engine of the same horse-power, probably some doubt arises as to whether the petrol engine really can do the same work as the heavier engine.

Horse-power is the rate of doing work, 1 h.p. is equal to 33,000 ft. lbs. of work done in one minute.

So long as the product of the force exerted in pounds, multiplied by the distance in feet through which the force acts in one minute is equal to 33,000, then 1 h.p. is being developed.

Each engine should, therefore, be capable of doing $33,000 \times 20$ ft. lbs. of work in one minute.

The gas engine would develop its power at a crank-shaft speed of, say, 200 r.p.m., while the speed of the petrol engine shaft would be about 1,200 r.p.m. If each engine transmitted its full power through a belt from a pulley keyed to the crank-shaft, the pulley being the same diameter in each case, then the petrol engine running at six times the speed would only be capable of exerting an effective pull in the belt equal to one-sixth that exerted by the gas engine.

Assuming that the resistance was not too great for the petrol engine, and that its speed kept steady at 1,200 r.p.m., then the horse-power developed would be the same in each case. If the resistance was too great for the petrol engine, and was exactly equal to that against which the gas engine had to work, the belt pulley would have to be driven through gearing which reduced its speed to $\frac{1}{6}$ or 200 r.p.m., and this would give an effective pull in the belt very nearly equal to that exerted by the gas engine.

A motor car engine must necessarily be of light construction, hence to develop its power a petrol engine is usually of the high speed type.

In order to be able to overcome big resistances such as are encountered when climbing a hill or starting a heavy vehicle into motion, the engine power is transmitted to the road wheels through gearing. The power developed at the road wheels is always less than the horse-power of the engine, due to friction losses in the transmission system.

The power output of a modern petrol engine is proportional to its speed of revolution, within very useful limits, say, 700 r.p.m. and upwards, thus the turning effort at the crank-shaft is practically constant.

Motor car engines develop full power at normal speeds of between 1,000 to 3,000 r.p.m., depending on the type of vehicle to which they are fitted. The power and general performance of petrol engines of given cylinder dimensions has increased considerably in recent years, due to larger valve diameters, better cam shapes, lighter reciprocating parts, higher compression pressures and piston speeds, more efficient ignition and lubricating systems, the use of ball and roller bearings in the working parts of the engine, and also largely due to the great improvement in carburettor design.

For taxation purposes, the brake horse-power formula evolved by the Royal Automobile Club for motor car engines of the four-stroke type, assumes that the mean effective pressure on the piston, during the power stroke, is 90 lb. per sq. in., and, assuming equal piston speeds of 1,000 ft. per minute for long as well as short stroke engines, the distance travelled by each piston in power strokes is thus 250 ft. per minute. The mechanical efficiency of the engine is assumed to be 75 per cent, and grouping these figures together in the form of a simple equation we get $\frac{90 \times \cdot 7854\ D^2 \times 250 \times N \times \cdot 75}{33{,}000}$ which on cancelling out gives $\frac{D^2N}{2 \cdot 5}$, or in mm. $\frac{D^2N}{1{,}613}$ as an expression for the determination of the b.h.p. of any multi-cylinder petrol engine.

The only variable quantities allowed for in this formula are the diameter of the piston, D ins., or mm. and N, the number of cylinders.

Incidentally, it is a very poor petrol engine that will

not give a b.h.p. in excess of that calculated from the R.A.C. formula.

For taxation purposes it is satisfactory enough, but as a means of determining the actual horse-power a well tuned engine can develop it is useless.

As a striking example of the high horse-power that can be developed by small bore petrol engines of modern design, it is interesting to mention that a four-cylinder Talbot-Darracq engine, having a total cylinder capacity of less than 1,500 cc., developed somewhat more than 50 b.h.p. As the bore of each cylinder is 65 mm. the horse-power by R.A.C. formula is only 10·5.

Analysing the actual performance of the engine, and taking the revolutions of the crank-shaft as 4,700 per minute ; as the piston stroke is 112 mm., the piston speed is thus 3,450 ft. per minute, while the mean effective pressure on each piston will be approximately 112 lb. per sq. in.

Three Talbot-Darracq cars fitted with exactly similar engines, finished first, second, and third in the J.C.C. 200-mile race at Brooklands in 1921, covering the track at an average speed of almost exactly 89 miles per hour.

It is not, however, suggested that a petrol engine of the dimensions given would live long when working under the strenuous conditions mentioned, but the example serves to show that the problem of charging the cylinders with combustible mixture has already been solved, and that future discoveries in metallurgical science will render possible the construction of high-powered engines of small cylinder capacity that will have a long life.

While many internal-combustion engines will develop more than their rated b.h.p., it is always well to have some power in hand, and this should be remembered when considering power requirements. Both gas and

oil engines function satisfactorily when running under light loads, but oil engines work better, and the cylinder interior keeps cleaner when an engine is given plenty of work.

With all engines, gas or oil, the highest fuel efficiency is obtained when they are working well up to their rated power, but overloading is to be deprecated except for very short periods, when it is perhaps unavoidable.

Petrol engines installed in a motor vehicle very rarely have occasion to develop their maximum b.h.p., and of course they last longer and the working parts run quieter as a consequence. The fuel efficiency of vehicle engines is not so uniformly high as that of stationary engines, owing to the constant changes in running conditions, such as rapid acceleration, engine racing, injudicious use of the throttle valve, and variation in ignition timing, etc. High fuel efficiency in this application of the petrol engine is thus sacrificed to convenience of speed and power control, and taking into consideration the small amount of trouble a vehicle engine gives and the exacting conditions under which it has to work, the fuel efficiency is remarkably good.

CHAPTER VII

AERO ENGINES

Views were expressed during the war that the rapid development of the petrol engine for aeroplanes would influence in some way the design of post-war engines for motor vehicle propulsion. An aero engine is about one-third of the weight of a motor car engine per horse-power developed ; its suitability for its work, combined of course with the finest materials and workmanship, is principally due to this feature of light weight.

Thus we find that nuts, screws, and spanner-tightened parts generally, are not of sufficiently robust proportions to stand the heavy hand of the ordinary motorist. The aero engine is a wonderful production, built to suit the conditions under which it has to work, but the light gauge material of water jackets, exhaust manifolds, etc., examples as they are of clever sheet metal and welding work, would not be suitable for motor vehicle engines.

For the cylinder construction of internal-combustion engines, of whatever type, cast iron is the most suitable material, as, besides the facility and perfection with which it may be cast into intricate shapes, it possesses admirable wear-resisting properties, is a good conductor of heat, and is superior to wrought iron or steel for withstanding the corrosive action of the exhaust gases that are discharged from all internal-combustion engines.

Accessibility for overhaul is not an outstanding feature of aero engines. Accessibility does not always conduce to compact and light construction. In some

aero engines the construction necessitates the removal of a cylinder to replace a valve. If an aero engine goes wrong in the air there is very little that can be done to put it right under flying conditions, and it is, of course, quite impossible to remove and replace a cylinder part.

The successful performance of aero engines depends on good tuning, frequent and expert overhaul and internal cleaning. As a unique example of continuous running, it is of interest to note that a Napier engine, in service each day on the London-Paris route, has completed a distance of 20,000 miles without being dismantled. The horse-power of an aero engine is many times greater than the horse-power required for the propulsion of the heaviest motor vehicle, hence the necessity for greater weight reduction is not a feature of vital importance in the latter case.

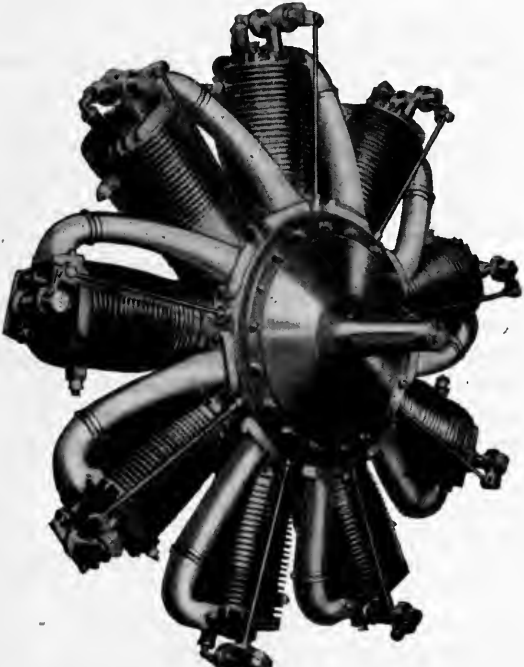
For the propulsion of aeroplanes the rotary engine had considerable vogue during the war. Because of its rotating cylinders it is self-cooling, and occupies less useful space in an aeroplane and is lighter than the vertical type of water-cooled engine.

These features render it especially suitable for the propulsion of small fast travelling and quickly- manoeuvered aeroplanes of the "Scout" type, and as a special engine for special requirements, the rotary engine has done excellent service, although it is not so economical in the consumption of fuel and lubricating oil as the more orthodox type of stationary cylinder water-cooled engine.

The illustration depicts a rotary Le Rhône aero engine, large numbers of which were manufactured in England by Messrs. W. H. Allen, Sons & Co., Ltd., of Bedford.

These engines were employed extensively on all fronts during the war, and were very largely used for the training of pilots both at home and abroad.

The rotary engine has been suggested as a type of air-cooled engine that could be suitably developed for motor car propulsion, but even now the majority of



W. H. Allen, Sons & Co., Ltd., Bedford

Fig. 11

LE RHÔNE ROTARY AERO ENGINE

90 H.P. at 1,200 R.P.M.

aero engines have water-cooled cylinders, despite the fact that an aeroplane engine is always moving through the air at high speed and under the best conditions for air-cooling to be effective.

It must however be remembered, that the power developed in each cylinder of an aero engine is necessarily much higher than in the case of a motor car engine.

Air-cooled engines are of simpler construction than when water-cooled; but except for light cars and motor cycles, air-cooling is not likely to displace water-cooling to any great extent.

As a rule, when a car engine is developing its maximum horse-power, such as when the vehicle is climbing a gradient, the air velocity is least effective.

To be effectively air-cooled, a multi-cylinder petrol engine must be provided with air jackets through which air is forced by means of a fan. This involves the installation of an air jacket system and the expenditure of otherwise useful power. Altogether the advantages of air-cooling are not realizable for engines mounted in a motor car chassis, besides which a rotary engine is not of a suitable shape to mount in a motor vehicle.

CHAPTER VIII

VAPORIZATION OF PETROL AND PARAFFIN

ALTHOUGH petrol and benzol are such easy fuels to vaporize, there is more ingenuity expended on carburettor design than on any other detail part of a petrol engine. Of course the carburettor is a most important part, on its correct functioning depends : the ease with which an engine can be started, its ability to run slow or fast for long periods and to accelerate from minimum to maximum speed in a few seconds, its pulling powers at all speeds on a low fuel consumption, in short its ability to function satisfactorily under the exacting and varying conditions of load and speed imposed on every motor car engine.

Carburettor designers aim at producing an automatic instrument, or one that will give a mixture of suitable quality under all conditions of engine speed and load, with a rich mixture at starting and for accelerating to full speed, as well as for slow running.

The discharge of petrol from a carburettor jet is caused by the reduction of pressure in the induction pipe when the engine piston moves out on its suction stroke, the pressure on the petrol in the float chamber being always atmospheric. When starting the engine from rest, either by hand cranking or by means of an electric motor starter, the speed of turning is too low to cause a discharge of petrol from the jet in the single jet carburettor illustrated in the diagram. Although the diagram illustrates, in simple outline, the principal parts of a spray carburettor, additional devices are

usually incorporated to enable the engine to fulfil the requirements mentioned.

Wherever the air passage in an induction pipe is restricted, and the engine is running, there the pressure is less than in a wider part of the pipe ; consequently, if the jet stands in this restricted space, petrol will be

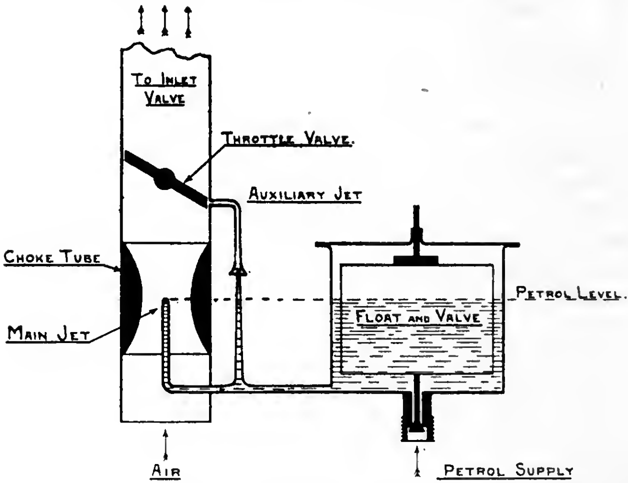


Fig. 12

SCHEME OF A SPRAY CARBURETTOR

more readily discharged than when the jet stands in a space of larger area.

By sufficiently reducing the area of the choke tube surrounding the jet, petrol will be discharged at the lowest speed of hand cranking, but unless this area is gradually increased as the engine speed increases when the throttle valve is further opened, the mixture passing to the cylinder will contain an increasing proportion of petrol vapour.

In actual practice the size of the main jet or jets and choke tube are such as will give the correct mixture at full engine speed with wide open throttle. It is not possible to reduce the area of the choke tube when it is made as in the diagram and the engine is running. With this type of carburettor, the slow running device consists of an auxiliary jet which discharges at the narrow passage between the edge of the throttle valve and the wall of the inlet pipe ; the throttle valve being nearly closed for starting and slow running.

In some carburettors a hollow cylindrical throttle valve is used to give the variable choke-tube effect, the jet discharging into a slot cut in the valve. When the throttle valve is full open the air flow past the jet is unrestricted, closing the valve reduces the area past the jet and so a suitable mixture is obtained for all conditions of running.

The temperature at which petrol and benzol freely give off an inflammable vapour at atmospheric pressure is well below freezing point. The actual temperature is termed the "flash point."

The next fuel in order of volatility is refined paraffin oil, the flash point of which is much above the normal temperature of the atmosphere, thus, compared with petrol and benzol, it is a safe fuel, and as it is considerably cheaper than petrol it is an attractive fuel.

Many attempts have been made, and indeed are still being made, to use paraffin oil as a substitute for petrol and with a certain success. The complete solution of the problem is, however, somewhat elusive.

The calorific value of paraffin oil is about the same as petrol, i.e. 19,000 to 20,000 B.Th.U. per lb., but unlike petrol, paraffin requires a temperature considerably

above the normal temperature of the atmosphere to vaporize it sufficiently freely for use in an engine cylinder.

The vaporization temperature must be kept fairly constant ; if the temperature is too low the charge is deficient in paraffin vapour, liquid particles of paraffin are carried into the cylinder and foul the sparking plug points, thus causing misfires. If the vaporizing temperature is too high, the paraffin is decomposed and carbon particles are deposited on the interior surfaces of the engine cylinder.

A further disadvantage of paraffin is that the combustible mixture is easily upset by alterations in the air supply, and unless oil engines of the Otto cycle type are kept working steadily under approximately full load, misfiring and incomplete combustion, with their attendant running troubles, result. Even with stationary engines of this type using paraffin oil as fuel, the combustion chamber walls and the piston head readily collect carbon, although, compared with a motor car engine a stationary engine works under much more uniform conditions of load and speed.

Paraffin finds its way past the piston rings and as it readily combines with lubricating oil it may destroy its lubricating properties.

Petrol and benzol are so free from sooting properties under all conditions of engine speed and load that it is not surprising to find that paraffin oil does not make much headway as a fuel for motor vehicle engines, where delays through engine trouble, which easily start with paraffin, cannot be tolerated.

Apart from the technical problem of satisfactory vaporization, the persistent odour attending the use of paraffin oil seems to permeate everything carried on the vehicle, and this is a feature decidedly objectionable

on passenger carrying vehicles. When paraffin is used as a motor vehicle fuel, the heat for vaporization is obtained by jacketing a portion of the carburettor and circulating some of the exhaust gases through the jacket, the engine being started from cold on petrol.

As the exhaust gas temperature will vary with the load and speed of the engine it will be realized that vaporization temperatures will vary through a wide range.

CHAPTER IX

FARM AND TRACTOR ENGINES

THERE is a steady demand for engines of from 2 b.h.p. upwards for driving farm and dairy machinery, pumps, dynamos for electric lighting, and other machines requiring moderate power.

Engines that will run on either petrol or paraffin are very popular for this class of work, and many firms have specialized in the production of single and multi-cylinder stationary engines of the motor car type. A useful set of this kind comprises a two or four cylinder engine of about 10 b.h.p., direct coupled to an electric generator for electric lighting, welding, etc.

These compact plants require very little attention, they start up readily on petrol without preliminary heating of the vaporizer, and as soon as this has become heated to a sufficiently high temperature by running on petrol for a short period, the fuel may be changed over to paraffin without stopping the engine.

These engines will run continuously for long periods and are very economical as regards fuel and lubricating oil consumption.

A cheap and useful type of horizontal single-cylinder petrol-paraffin engine is built in sizes from 2 to 10 b.h.p. These are suitable for driving chaff or root cutting machines, milk separators, churns, circular saws, etc., and being fitted with what is called hopper cooling, they are self-contained and easily portable.

Hopper cooling dispenses with the need for a continuous water supply; the hopper is simply a rectangular box continuation of the cast iron water jacket,

The Saunderson Tractor and Implement Co., Ltd.

Fig. 13

THE SAUNDERSON UNIVERSAL TRACTOR

and calls for no attention beyond occasional replenishment of water as it is evaporated by heat from the engine cylinder.

The power requirements of the farmer are best met by the tractor or general purpose power plant, as this machine, in addition to being able to drive what may be called the stationary machines about a farm, is able to carry out, more expeditiously and economically than horse teams, the heavy work of land cultivation which forms perhaps the most important class of work to be done, as well as general haulage work over country roads.

Tractor engines are usually about 20 b.h.p., and are of either the two or four-cylinder type. They are of more robust construction than a motor car engine; they develop their power on paraffin oil and run at a lower crank-shaft speed than the latter.

A 25 b.h.p. tractor engine, when operating through suitable gearing, will exert a drawbar pull of about 3,000 lb., the winding-drum pull being 9,000 lb. It is usually capable of hauling 5 to 6 tons over a good macadam road on a fuel consumption of approximately 3 miles to the gallon, and when ploughing 3 to 4 furrows the consumption is approximately 3 gals. per acre, under average conditions, and 6 in. deep, at a rate of three-quarters of an acre per hour.

It is not possible to give exact figures for the performance of an agricultural tractor as land conditions vary immensely. Everyone interested in land cultivation and farm work generally, cannot do better than study the performance of the various tractors in the Royal Agricultural Society's annual trials, as well as those organized by the Society of Motor Manufacturers and Traders.

Although gas and oil engines function in a variety of

ways and differ considerably in the arrangement of important details, according to the ideas of their designers and to suit special power requirements, the cycles on which they operate have remained unchanged for a number of years. As previously mentioned, in all gas and petrol engines, the fundamental principle of the Otto cycle, "compression of the combustible

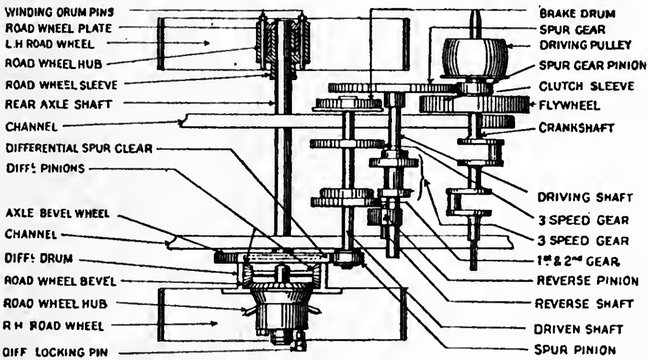


Fig. 14

TRANSMISSION GEAR OF SAUNDERSON TRACTOR

mixture by the engine piston," is adopted exclusively; the same principle is also adopted with engines using refined paraffin oil. Otto cycle paraffin engines compress the mixture to a comparatively low pressure, i.e. 50 to 70 lb. per sq. in., this being necessary so as to avoid spontaneous ignition of the charge during the compression stroke, which may occur owing to the mixture being necessarily above atmospheric temperature at the commencement of compression. Ignition of the charge is accomplished by either hot tube, hot cylinder head, or by means of electric sparking devices.

For stationary engines and for farm tractor and launch engines operating on the Otto cycle, refined paraffin oil is a fairly satisfactory fuel, as in these installations the load on the engine is comparatively constant, and personal contact with the fuel vapour is not so intimate or objectionable as is the case on a passenger-carrying vehicle.

CHAPTER X

DEVELOPMENT OF ROAD TRANSPORT

For the propulsion of passenger-carrying vehicles which run on ordinary roads, as distinct from vehicles running on rails, the petrol engine has no competitor.

The petrol-engined vehicle does practically the whole of the light goods transport work, involving the carrying of loads up to, say, 3 tons, as well as a large share of the heavy goods transport; but for the carrying of loads above 3 to 5 tons, the steam wagon and tractor compete with the petrol lorry, in some cases with success, on the score of lower fuel cost.

Of late years public service passenger-carrying vehicles, such as motor rail coaches, light locomotives, chars-à-bancs, and motor buses have attained to a remarkable degree of popularity, and innumerable regular services are operating successfully in competition with local railway services.

Unless legislation interferes, passenger and goods transport by public service motor vehicles will develop enormously. Cheap and rapid transport of everything is the key to industrial prosperity, and it will be admitted that the present arrangements are not satisfactory.

That motor bus services are a commercial proposition when efficiently organized is already recognized, and this system of service will increase in popularity, especially in new districts in which electric-car services have not been established.

An electric car service derives its power from stations equipped with engines, dynamos, and auxiliaries; but as large and economical power units are installed to

provide current for lighting as well as power purposes, the cost of power production is kept reasonably low.

Electric power has to be transmitted by means of overhead equipment throughout the whole length of the track, and of course the track has to be provided as well as the cars and their propelling machinery. Upkeep expenses and running costs are heavy, and in many towns existing services are inadequate, largely owing to the fact that routes are fixed when the rails are originally laid down.

A motor bus carries its own power station, it is not confined to any particular route, and this may be changed at will until the one giving the best service is found. The number of buses on any route may be added to as circumstances demand, without consideration of power station limitations.

The carrying capacity of a motor bus, as at present constructed, is less than that of an electric car, but the difference can be rectified. Motor bus construction is continually improving, and with the perfecting of power transmission systems from engine to road wheels, the ordinary objections to these vehicles are rapidly disappearing. The possibility of using cheaper fuels than either petrol or benzol for high-speed engines has not yet been fully investigated; various systems are designed to enable refined paraffin oil to be used in motor car engines, but as already pointed out, the use of paraffin in Otto cycle engines which have to work under the exacting conditions of road vehicle service, is not a success. For vehicle propulsion the essential feature in an engine is flexibility, and with petrol and benzol fuels this feature is realized to perfection without detriment to the engine as regards its reliability of service.

The successful use by high speed engines of such

fuels as refined paraffin, Diesel engine oil, or even a mixture of these, would, by reducing running costs, add enormously to the popularity of the internal-combustion engine for road and rail transport work. The only possibility of using such fuels seems to lie in the adoption of some form of Diesel or semi-Diesel cycle, and experiments are being made in this direction.

The design of small cylinder high revolution Diesel engines is not a simple matter, for example, small capacity cylinders will necessarily have a small clearance volume, and this renders difficult the efficient spraying of the injected charge so as to ensure ignition and complete combustion. The enclosing surface area of small cylinders is greater in proportion to the volume enclosed than in the case of larger cylinders, thus the cooling effect will be greater. As ignition depends on the temperature attained at the end of the compression stroke, the compression pressure in the smaller cylinder will have to be higher than is usual in larger Diesel engines of the slow-running type.

High-speed high-compression engines will not run at the same low speeds as low-compression engines, and as in Diesel engines the compression pressure must be constant in order to get ignition to take place, flexibility and slow running can only be obtained by having a large number of cylinders and carrying a heavy fly-wheel on the crank-shaft.

The quantity of oil to be sprayed into each cylinder of a high-speed engine of the motor car type for each power stroke, would be very small indeed, even at full load, and as speed and power regulation will be controlled by the amount of fuel supplied per stroke, injection and measuring mechanisms must operate with great exactness.

Injection orifices will be of minute dimensions and elaborate filtering arrangements will be necessary.

In a four-stroke engine of the Diesel type the difficulty of accommodating the necessary valves in so small a cylinder head is a very real one.

Taking into consideration all the points mentioned, it would appear that the two-stroke semi-Diesel engine, with its lower compression pressure and simpler cylinder construction, is a more likely solution of the problem.

The Société Peugeot have recently produced what may be defined as a modified form of semi-Diesel engine for road vehicles.

This engine has two cylinders, 120 mm. bore by 150 mm. stroke, and it is said to develop 50 h.p. at 1,000 r.p.m. It operates on the two-stroke cycle, carries a compression pressure of about 300 lb. per sq. in. and has a special form of combustion chamber which, after the engine has started, retains sufficient heat to vaporize and ignite the injected fuel.

For vaporization and ignition purposes when the engine is started from cold, and when the combustion chamber walls are not hot enough, electrically heated plugs are provided. These plugs are of similar design but smaller than those now used for starting semi-Diesel engines of the slow speed type. The arrangement seems to be quite a reasonable proposition, and useful results have been obtained.

CHAPTER XI

DIESEL AND SEMI-DIESEL ENGINES

UNTIL recent times, oil engine manufacture was largely in the hands of agricultural implement makers, presumably because their productions are supplied to farmers, contractors, country house people and others, who are able to make good use of the advantages possessed by the oil engine, and to whom the ordinary sources of gas and steam power are not, perhaps, available or suitable.

A few years ago, low-compression Otto cycle engines of the horizontal slow-speed type using refined paraffin oil as fuel were very popular for this class of work, and are still in demand but to a decreasing extent, owing to the development of the petrol engine and the so-called semi-Diesel engine.

The feature that has brought the oil engine to its present high state of development is that of compressing only the air necessary for combustion, and injecting the charge of oil at the end of the compression stroke.

Concentration on this principle, which comprises engines of the Diesel and semi-Diesel class, has given results which place the heavy oil engine in the front rank for all power purposes, except vehicle and aeroplane propulsion, primarily because they are more reliable and are able to burn successfully, crude, residual, and tar oils, on a lower fuel consumption than is possible with Otto cycle engines using more refined and expensive oils.

Diesel and semi-Diesel engines are built to operate on both the two and four-stroke cycles ; in construction

they are similar to gas engines but of heavier build, and they use liquid fuel exclusively, this being injected and ignited spontaneously at the end of the compression stroke. In all types of Diesel and semi-Diesel engines

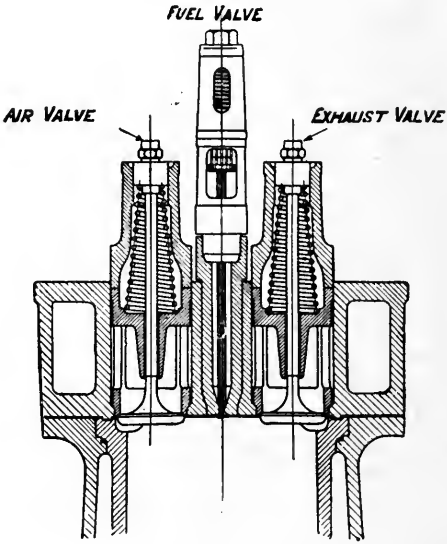


FIG. 15

CYLINDER HEAD AND VALVES OF A FOUR-STROKE DIESEL ENGINE

a mechanically-operated fuel admission valve is a necessary part and calls for much ingenuity in design. Each cylinder of a four-stroke Diesel engine is fitted with an air inlet valve, a fuel valve, exhaust valve, and an air starting valve. A two-stroke Diesel cylinder will have a fuel valve, an air starting valve, and one or more air scavenging valves. Air admission and

exhaust ports are provided in the cylinder wall; these are controlled by the main piston as in two-stroke gas engine practice.

The majority of semi-Diesel engines operate on the two-stroke cycle, with air admission and exhaust ports in the cylinder wall. The cylinder head valves usually comprise one or more fuel admission valves and an air starting valve.

In 1890, five years before Diesel patented the self-igniting oil engine, Akroyd-Stuart took out a British patent and built engines in the cylinders of which air only was compressed, the charge of oil being injected into the combustion chamber at the end of the compression stroke.

For some reason, such engines are now commonly called semi-Diesel engines, although to Akroyd-Stuart is undoubtedly due the credit of being the first inventor and constructor of engines of this type.

The main feature of difference between a Diesel and semi-Diesel engine may be explained as follows—

In a Diesel engine air only is taken into the cylinder during the suction stroke, and compressed by the piston until its temperature is high enough without any other source of heat to ignite the charge of oil, which latter is sprayed into the combustion chamber when the piston is at the end of the compression stroke.

In a semi-Diesel engine air only is taken into the cylinder during the suction stroke, but as the designed compression pressure and resulting air temperature is too low to ignite the oil spray, a hot metal surface, such as an uncooled portion of the cylinder head, is maintained at a temperature high enough to vaporize and ignite the charge of oil sprayed into the combustion chamber at the end of the compression stroke (Fig. 16).

By delaying the admission of oil into the cylinder until the compression stroke is completed, the compression pressure may be raised to any desired value without pre-ignition of the charge occurring.

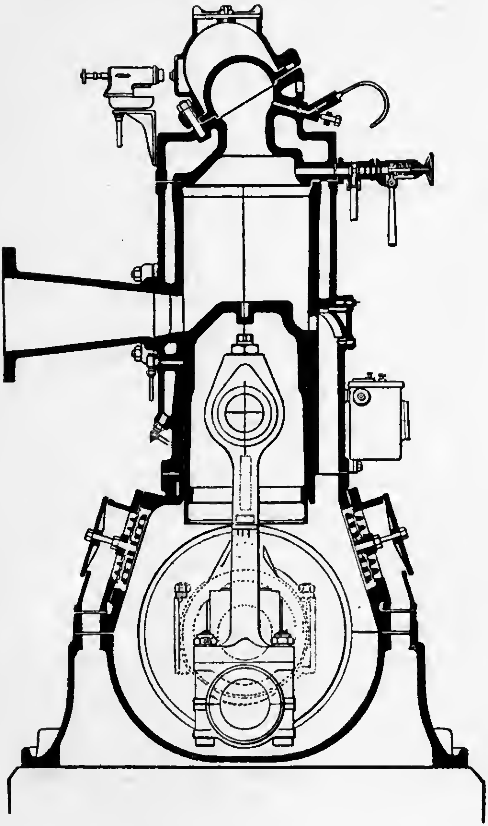
Thus the air may be compressed to such a high pressure and temperature that the oil is vaporized and ignited in a far more reliable manner than in Otto cycle engines, where special vaporizers and electric ignition devices have to be provided.

Of the greatest importance is the fact that by raising the compression pressure, the fuel economy is considerably increased above that of oil engines operating on the Otto cycle.

In what may be called the standard type of Diesel engine, the compression pressure is usually 450 to 500 lb. per sq. in., and at this pressure, although the cylinder head and barrel, and in large engines the piston also, are water cooled, the temperature of the air at the end of compression is about 1,000° Fah.

This temperature is high enough to ignite any of the paraffin series of oils sprayed into the cylinder, Some difficulty, however, is experienced in the ignition of tar oils (as they have a lower hydrogen content) when these are used without a small quantity of ignition oil having a lower ignition temperature.

In the standard Diesel engine, fuel oil is delivered to the fuel valve casing by means of a plunger pump. Inside this casing, and surrounding the fuel valve (*see* Fig. 15), a series of perforated discs of steel are fixed, the arrangement forming an atomizer. A pipe conveying air at a pressure of from 550 to 1,000 lb. per sq. in., depending on the load on the engine and the viscosity of the oil used, is in constant communication with the fuel valve casing. This compressed air is supplied from a receiver, termed a blast bottle, the air in which is maintained at



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Robey & Co., Ltd.

Fig. 16

SECTION THROUGH A ROBEY SEMI-DIESEL ENGINE

the required pressure by an air compressor driven by any suitable means. The fuel pump delivers its charge of oil into the fuel valve casing against the air pressure always existing there, and the oil delivered becomes entangled in the holes in the perforated discs. When the fuel valve is opened by its cam, the oil is blown into the cylinder by the pressure of the blast air and enters the cylinder in a fine spray, due to the action of the blast air sweeping the entangled oil through the perforated discs. In this state it readily ignites, and as the period of oil admission is usually designed to occupy about one-tenth of the piston stroke, under ordinary working conditions the maximum pressure of combustion does not exceed the compression pressure, i.e. 450 to 500 lb. per sq. in.

The "air injection" system gives remarkably good results, and although at present it is the most popular system of fuel injection for Diesel engines, many successful engines are now using "solid" injection, that is the oil is sprayed into the engine cylinder under the direct action of a plunger pump only.

The solid injection system has advantages in that it dispenses with the need of high pressure air compressors, receivers, coolers, valves, piping, etc., with their attendant disadvantages. Success with some of these solid injection systems at present in use is so pronounced that it seems likely to become universal in the near future. Solid injection systems are used almost universally on semi-Diesel engines. In this application, however, as will be explained, the problem is somewhat simpler.

In a Diesel engine that has no uncooled surfaces, it is essential that the fuel oil should be sprayed in such a shape as to spread itself in a finely-divided state through the volume of high temperature air in the

combustion chamber, so as to vaporize and ignite without delay.

If not effectively sprayed misfiring and delayed ignitions occur, due to sluggish vaporization and burning of the coarse particles of oil discharged through the fuel valve orifice. This causes pre-ignition, and knocking may occur to a dangerous extent. With air injection atomization is very satisfactory, but with solid injection the difficulty is to maintain effective spraying of the discharged oil over long periods of running.

With solid injection the discharge orifices are of small size, and thus it is necessary to thoroughly filter the fuel oil before it reaches the pumps. In order to thoroughly break up the oil, pump discharge pressures of from 2,000 to 10,000 lb. per sq. in. are necessary with Diesel engines of the solid injection type.

A Diesel engine readily starts from all cold without preliminary heating of any part of the combustion chamber, but in a semi-Diesel engine, owing to the lower compression pressure, 150 to 250 lb. per sq. in., the temperature attained at the end of compression is not high enough to start the engine without first heating some portion of the combustion chamber ; which may be a part of the cylinder head.

Preliminary heating is usually carried out by means of a lamp, applied externally to the head of the combustion chamber for a few minutes before starting. After the engine has been running for a few minutes, the heat from combustion in the cylinder is sufficient to maintain the uncooled portion of the vaporizer at a high enough temperature to give regular ignitions without using the lamp.

The provision of a hot bulb or uncooled portion of cylinder surface in semi-Diesel engines is, to some extent, a source of constructive weakness ; this feature

and the necessary preliminary heating of each cylinder head by means of a lamp, or providing electrically heated plugs, and in the case of large cylinders the provision of air scavenging valves, add to the difficulty of constructing high power multi-cylinder semi-Diesel engines.

The two-stroke semi-Diesel engine, as constructed to develop a maximum of, say, 100 b.h.p. per cylinder, is probably the simplest and cheapest type of oil engine built for moderate powers ; attempts to greatly increase the power output per cylinder by the addition of valves do not seem worth while, in view of the successful operation and proved success of low pressure Diesels of the two and four-stroke type.

CHAPTER XII

HEAVY OIL STATIONARY ENGINES

THE normal pressure to which the air is compressed in an orthodox type of Diesel engine cylinder is, as previously stated, 450 to 500 lb. per sq. in. by gauge, and this gives an air temperature of approximately 1,000° Fah.

In order to reach this temperature, the volume of the clearance space or combustion chamber is one fifteenth of the total cylinder volume, which latter is the volume of the combustion chamber, plus the volume swept out by the piston. As the combustion chamber is usually a direct continuation of the cylinder bore, the inner surface of the cylinder cover flat, and the top of the piston but slightly dished, the cooling effect of the wall surface is considerable. If cylinder cooling could be entirely eliminated, and also the cooling effect of the blast air, with the same clearance volume, the temperature attained at the end of compression would be about 1,300° Fah.

By so shaping the combustion chamber as to reduce the cooling surface to the minimum possible, consistent with good design, and using solid injection, it has been found that a compression pressure of only 300 lb. per sq. in. gauge is high enough to give an air temperature at the end of compression well above that required to vaporize and ignite the sprayed charge.

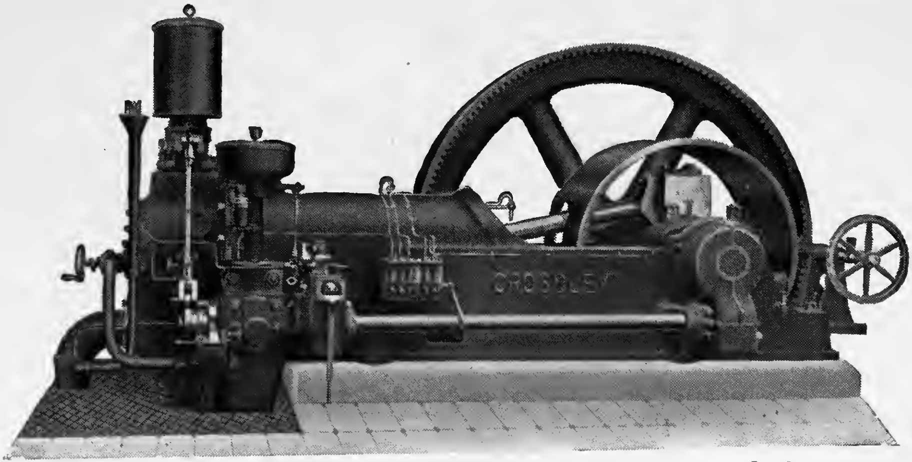
An engine embodying the features of low compression and solid injection, with the ability to start immediately from the cold state, would seem to represent the simplest construction possible for a heavy oil engine.

It is an advantage, from a practical point of view, to keep cylinder pressures as low as possible, while still maintaining good fuel economy, and with this idea in view the low compression, cold starting oil engine has been developed. If through faulty functioning of the fuel valve, ignition should occur before the compression stroke is completed, pressures of more than twice the pressure of compression may occasionally be generated in the cylinder, and it is for this reason that Diesel engines are of more massive construction than gas engines, in which the possible maximum pressures are much less.

The most interesting part of the Crossley cold starting four-stroke engine is the combustion chamber, This, it will be noticed, is in shape somewhat resembling a flattened sphere. The air inlet and exhaust valves are located in the centre, and in the same vertical axis ; the oil spray valve is at right angles to the air and exhaust valves, and the piston head is formed by a projecting cone and cylinder (Figs. 18 and 19).

When at the end of the compression stroke, the cylindrical portion of the piston head enters the parallel neck in the combustion chamber. The high velocity of the air through the annular passage thus formed when the piston is reaching this position, has considerable effect in creating turbulence, so distributing the oil spray and flame as to give rapid and complete combustion.

Horizontal engines of any type (excluding petrol engines) are by reason of the large floor space they occupy suitable only for stationary power purposes. As all the so-called Diesel engines built in this country, whether for stationary or marine purposes, have been of the vertical type, the name Diesel applied to a horizontal engine does not sound familiar. It would appear,



Crossley Bros., Ltd.

FIG. 17

THE CROSSLEY COLD-STARTING HEAVY-OIL ENGINE

however, that any cold starting engine that carries a sufficiently high compression pressure to ignite the injected fuel, is different from a Diesel engine only if solid or airless injection is used, in which case combustion occurs partly at constant volume and partly at constant pressure, whereas with air injection constant pressure combustion results.

The fuel consumption of the Crossley low-compression

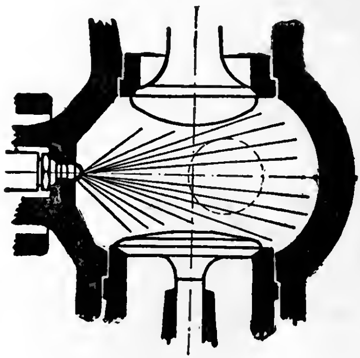


Fig. 18

AIR INLET, EXHAUST AND FUEL VALVE OF CROSSLEY OIL ENGINE

engine is remarkably low, as evidenced by Professor Burstall's test results reproduced in the table on page 76.

The Ruston cold starting engine is fitted with solid injection and carries a compression pressure of about 420 lb. per sq. in. The consumption of average quality fuel does not exceed 0·48 lb. in the smaller engines and is as low as 0·42 lb. per b.h.p. hour in the higher powered engines.

The ability of Diesel and semi-Diesel engines to run satisfactorily on the cheapest fuel oils renders them economic propositions for a variety of purposes where moderate power units are required.

The applications comprise the driving of dynamos,

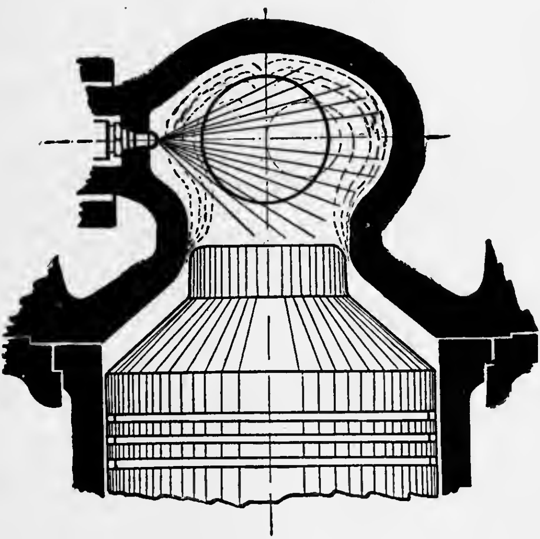


FIG. 19

ILLUSTRATING TURBULENCE IN THE CYLINDER

pumps, mill machinery, etc., and as auxiliary power in stations where steam or gas engines of high power are already in operation.

For these purposes, advantages such as the ability to start instantly from the cold state and give full power output in a few minutes, low fuel consumption at light loads, the absence of stand-by losses, small floor space required, general ease of installation, operation, and

SUMMARY OF TESTS MADE BY PROFESSOR BURSTALL ON A CROSSLEY LOW-COMPRESSION OIL ENGINE

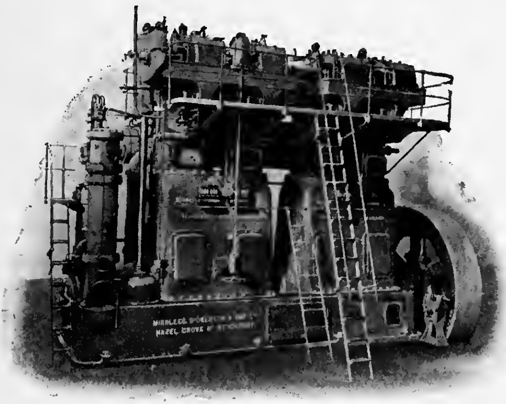
Normal rated load 117 b.h.p. at 180 r.p.m.
Cylr. : 18½″ Bore × 28″ Stroke

Fuel.	B.h.p.	Oil, b.h.p., the Hour. Pounds.	Heat Units, b.h.p., the Hour. B.Th.U. (lb.-Fahr.).	Thermal Efficiency on the b.h.p. Per cent
KEROSENE. Calorific Value 18,500 B.Th.U. per lb.	145·0 (24 per cent Overload).	0·432	7992	31·84
	123·0	0·427	7899	32·22
	96·0	0·424	7844	32·44
	61·3	0·455	8417	30·23
	29·8	0·627	11599	21·93
	0	9·46 lb. the hour.	—	—
RESIDUAL PETROLEUM. Calorific Value 18,000 B.Th.U. per lb.	142·0 (21 per cent Overload).	0·457	8226	30·93
	125·0	0·425	7650	33·26
	96·7	0·424	7632	33·35
	30·9	0·647	11646	21·85
	0	11·0 lb. the hour.	—	—
TAR OIL. Calorific Value 16,200 B.Th.U. per lb.	146·0 (25 per cent Overload).	0·514[1]	8420	30·22
	129·0	0·504	8207	31·01
	102·0	0·475	7750	32·84
	67·0	0·488	8140	31·26
	32·0	0·700	11850	21·47
	0	10·16 lb. the hour.	—	—

fuel handling, and the absence of ashes, are all features that strengthen the claims of the oil engine as a power producer for stationary work.

[1] These figures include a small proportion of kerosene used for ignition purposes.

Mr. Chas. Day gives the following figures for fuel consumption as easily obtainable in ordinary everyday working of a Mirrlees-Diesel engine of moderate power,



Mirrlees, Bickerton & Day, Ltd.

FIG. 20

FOUR-CYLINDER 500 B.H.P. MIRRLEES-DIESEL ENGINE

and the author can testify that these do not increase after years of work.

Full load	=	·45 lb.	per	b.h.p.	hour.
$\frac{3}{4}$,,	=	·47	,,	,,	,,
$\frac{1}{2}$,,	=	·53	,,	,,	,,
$\frac{1}{4}$,,	=	·70	,,	,,	,,

If the average consumption of a heavy oil engine be taken as ·5 lb. per b.h.p. hour and that of a steam engine plant (including auxiliaries) as 2·25 lb. of coal per b.h.p. per hour, this makes the oil engine a profitable proposition even with fuel oil at four times the price of coal.

An interesting comparison between the cost of running a Diesel engine plant and a steam plant is given in a report by the electrical engineer to the Southend Corporation.

Over a period of six months' working, the cost per unit generated by the Diesel engine plant in operation at one of the sub-stations works out to be 1·85d., while the cost per unit generated by the steam plant at the main generating station is given as 3·29d.

Interest and sinking fund charges are included in the above figures.

The price of both coal and oil fuel has been subject to such violent oscillation in recent times, that running costs cannot be predicted with any degree of certainty.

Normally, fuel costs are distinctly in favour of the oil engine, at any rate for marine propulsion, and it is in this application that rapid developments are now taking place.

CHAPTER XIII

MARINE OIL ENGINES

HUNDREDS of ships are now propelled by oil engines developing from 1,000 to 3,000 i.h.p. on a single shaft, and a wealth of ingenuity is apparent in the design of important detail parts of engines of the same type but by different builders.

In the high-powered units which comprise multi-cylinder engines of the marine Diesel class, we find that the four-stroke cycle, single-acting engine is most popular. Next in popularity comes the two-stroke single-acting engine, an important development of which is the opposed-piston type.

The decision to concentrate on the construction of a particular type of engine is naturally not made by any firm until they have found, by experiment and as the result of experience, that in design and operation the resulting product is a satisfactory commercial proposition.

When considering the various engines which operate on the cycles mentioned, this fact should be remembered, as, while one type may apparently possess advantages over another, it will be found that when all the features are considered, compensating advantages render a definite statement, one way or the other, difficult to make.

Ever since the internal-combustion engine became a commercial proposition, engines operating on the four-stroke cycle have been in the majority, and have served the purpose of proving the general reliability and economy attending the use of gas and oil engines of all sizes.

The established position of the Diesel engine is due to the good work done by four-stroke engines, and for stationary power purposes where strict economy of space is not such an important matter, so satisfactory is it that arguments against the four-stroke engine are not entirely convincing.

Respecting the design of oil engines of a power suitable for the propulsion of ships that would normally be fitted with steam engines, economy of space is a feature that must be considered.

Theoretically, it is possible to obtain the same horse-power from a single-cylinder two-stroke engine, as from a two-cylinder engine of the same cylinder dimensions and shaft speed, but of the four-stroke type. Thus the overall length of multi-cylinder engines developing the same horse-power is less in the case of the two-stroke, and this is a strong argument in favour of its use for marine propulsion.

The four-stroke engine combines in its construction a greater number of working parts than any other type, and as will be realized from the descriptions given in Chapter XI, the two-stroke engine certainly does show to advantage by reason of the small number and simple construction of its bearings and working parts generally.

The successful design of large engines centres in the ability of the designer to provide for the uniform cooling of the cylinder, cover, and piston, and to avoid hot spots; so that overstressing, distortion, and fracture of these parts, due to the great temperature difference between the gas-heated inner surfaces, and the water-cooled outer surfaces of the cylinder metal, does not occur.

Although four-stroke gas engines whose single piston area is much greater than that of the largest Diesel engines are satisfactorily constructed, the problem is

not more difficult owing to the lower temperature and pressure conditions in a gas engine cylinder.

The maximum pressure developed in the cylinder of a Diesel engine, under normal working conditions, is not in excess of the highest possible pressure that may, under abnormal conditions, be generated in a gas engine cylinder. On occasion, however, pressures so high as 1,000 lb. per sq. in. may occur in the cylinder of a Diesel engine, and these high pressures, infrequent though they may be, have to be provided for in the cylinder design.

In the four-stroke Diesel engine as now built, satisfactory cooling arrangements are, of course, provided, but as the cylinder head carries an air inlet, exhaust, air starting, and fuel valve, with sometimes a relief valve in addition, all fairly close together, the design of a cylinder head incorporating the necessary valve holes and cooling-water passages is not a simple matter.

Large diameter cylinders require suitably large valves, or several smaller ones, to give sufficient area for the passage of the greater volume of air and exhaust gases, and this adds to the complication and cost of the operating mechanism.

Exhaust valves require frequent grinding to their seats, and the valve operating gear must be so arranged as not to interfere with the quick removal of any of the valves should occasion arise.

Large gas engines are built with horizontal cylinders, and as the combustion chamber is much larger than in a Diesel engine and not necessarily of such a regular shape, the gas mixture and exhaust valves are located at the end of the cylinder barrel.

In a marine Diesel engine of the four-stroke type the valves are most conveniently situated in the cylinder head, and it will be realized that a combination of all

the features mentioned limit the diameter of cylinder that may be used.

In a two-stroke engine the exhaust valve as such is dispensed with, as also is the combustion air inlet valve; the main piston functioning as a valve for exhaust and inlet as in two-stroke Otto and semi-Diesel engines.

As the exhaust valve of a four-stroke engine remains open during at least one complete stroke of the piston, practically all the products of combustion are ejected to the atmosphere. On the suction stroke, as a result of the complete ejection of the exhaust gases, a charge of cool air practically undiluted by exhaust products enters the cylinder, and at the end of compression complete combustion of the sprayed charge of oil results.

In a two-stroke engine, exhaust and air admission takes place while the piston is at the outer end of the cylinder, thus the interval of time allowed for these two operations is considerably less than in a four-stroke engine.

In order to scavenge the cylinder of the waste products of combustion and to fill it with air for combustion of the injected oil, in some of the larger engines air inlet valves are provided in the cylinder head.

When the piston has uncovered the exhaust ports situated at the lower end of the cylinder, the air inlet valves are opened and air at a pressure of 2 or 3 lb. per sq. in. enters, scavenges the cylinder of exhaust gases and fills it with clean air which is compressed when the piston rises and covers the exhaust ports.

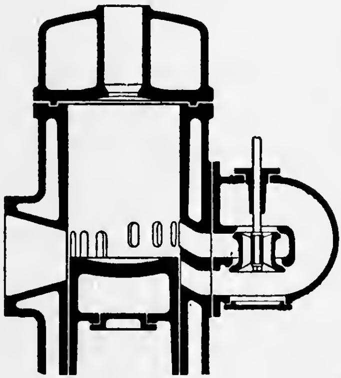
The system of cylinder port scavenging and air supply reduces the number of openings otherwise required in the cylinder head, and thereby simplifies the shape of this important part.

Only one opening is required in the cylinder head of the two-stroke Sulzer engine. This opening is in the

centre and accommodates both the fuel and air starting valves.

Scavenge and combustion air enters the cylinder through ports at the bottom; flow through these is controlled by the piston in the usual way, but an ingenious port system is adopted, there being two rows of scavenging air ports in the cylinder wall, opposite to the exhaust ports (Fig. 21).

On the downstroke of the piston, the upper row of



Sulzer Bros.

FIG. 21

SECTION THROUGH CYLINDER OF TWO-STROKE SULZER ENGINE

air ports are first uncovered, but as the air supply to these is controlled by a valve, and at this instant the valve is closed, exhaust gases cannot enter the scavenging air receiver.

On further movement of the piston downwards, the exhaust ports are uncovered and the pressure in the cylinder instantly falls to practically that of the atmosphere. The lower row of air ports are next uncovered

by the piston and scavenging begins; about the same time the valve opens and air enters the cylinder through the upper row of ports. The combined action of the two separate air streams insures very efficient scavenging, and as the exhaust ports are closed before the top row of air ports, the cylinder receives a full charge of clean air at a pressure above that of the atmosphere.

CHAPTER XIV

OPPOSED-PISTON OIL ENGINES

REMARKABLY good results have been obtained from two-stroke oil engines of the opposed-piston type, recently developed and built in this country. Opposed-piston gas and petrol engines are not a new development, but as in marine engine practice the object is to obtain as much power as possible with the minimum number of cylinders and cranks, the opposed-piston oil engine has attractive possibilities. Such engines are necessarily higher in overall dimensions than single piston engines of either the two or four-stroke type, but this is not a great disadvantage in a marine engine.

In addition to developing twice the horse-power per cylinder as compared with a single acting two-stroke engine of the same cylinder dimensions and piston speed, in an opposed-piston engine the pistons themselves are the cylinder covers. This is an advantage for constructional as well as thermal reasons, as will be appreciated.

Fuel and air starting valves communicate with the combustion chamber through the cylinder wall at the centre of its length, and as the volume of the combustion chamber is twice that of a single piston engine of the same bore and stroke, the "bulked" form of the chamber lends itself to effective combustion of the sprayed charge, with the minimum of heat loss to the cylinder walls and pistons.

As only two types of opposed-piston oil engines are commercial propositions at present, they cannot well be discussed in general terms, especially as individually

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the two engines differ considerably in features of design and operation.

The Cammellaird-Fullagar engine is unique in that although each cylinder has two pistons which move in opposite directions, a two-cylinder engine with its four pistons has only two cranks (Fig. 22).

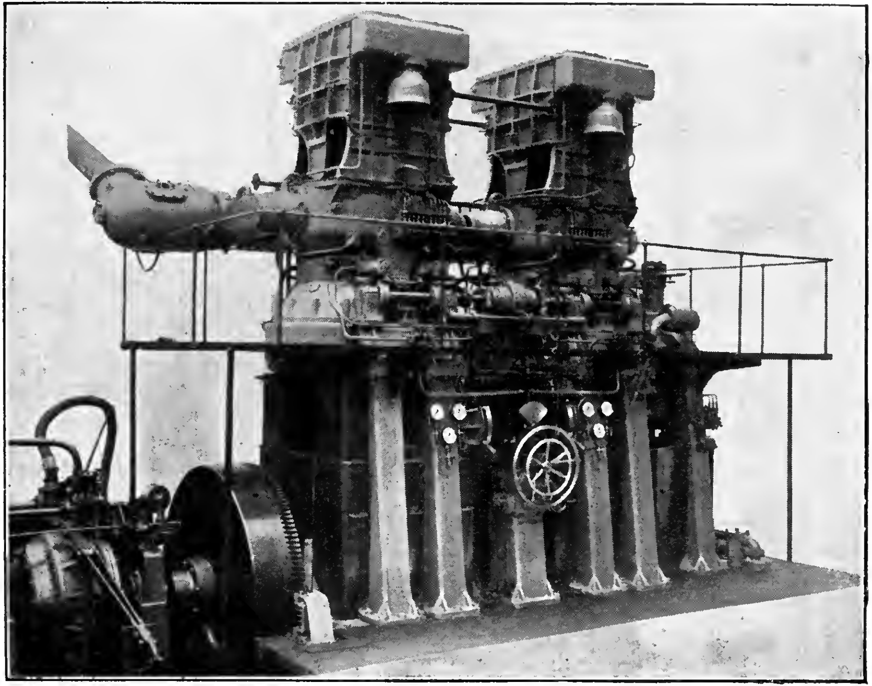
In a two-cylinder four-piston engine of this type the crank pins are at an angle of 180° to each other ; both the upper and lower pistons are attached to their own crossheads, and in each case the lower crosshead of one cylinder is connected by means of a diagonal coupling rod to the crosshead of the upper piston in the adjacent cylinder. The cranks are close together with no intermediate bearing between each pair. As a consequence the obliquity of the diagonal coupling rods is not excessive, and each pair of cylinders may be placed very close together.

For the supply of scavenge air a rectangular plate or piston is attached to the top crosshead of each cylinder, and as the top portion of the cylinder casting is closed in and fitted with suction and delivery valves, a simple and effective low pressure air compressor is obtained.

The scavenge air, at a pressure of about 2 lb. per sq. in., passes from the compressor to a chamber which surrounds the lower ring of ports in the cylinder wall, the opening of the ports being controlled by the lower piston.

The exhaust ports are at the top of the cylinder, and are first uncovered by the upper piston when it is nearly at the top of its stroke. As soon as the exhaust ports are uncovered the exhaust gases escape, and the pressure in the cylinder falls to practically that of the atmosphère.

When the pressure at the end of exhaust is atmospheric, the air inlet ports are uncovered by the lower



Cammell Laird & Co., Ltd.

Fig. 22

CAMMELLAIRD-FULLAGAR OPPOSED-PISTON MARINE ENGINE

piston, which will then be nearly at the bottom of its stroke.

This arrangement of cylinder ports is common to opposed-piston engines, and is an excellent one because the scavenge air, entering through the lower ring of ports, sweeps out the exhaust gases through the upper ports and fills the cylinder with fresh air.

In the Cammellaird-Fullagar engine the fuel is injected to the cylinders by high pressure air as in orthodox Diesel engines.

Distinctive features of the Doxford opposed-piston engine include: the method of giving motion to the upper piston, a low compression pressure, and the use of solid or airless injection for the fuel charge.

For giving opposite motion to the two pistons in each cylinder, three cranks are used, the centre crank being at 180° to the two outer cranks.

The centre crank is connected to the lower piston by means of a single connecting rod and crosshead in the usual way, while the upper piston is connected by side rods to lower crossheads, one on each side of the cylinder. Connecting rods from the two outer crank pins are attached to the lower crossheads, and thus motion is given to the upper piston.

The low compression pressure of 300 lb. per sq. in. is rendered a practical proposition by first sending steam through the cylinder jackets before starting the engine from cold. This enables a sufficiently high air ignition temperature to exist in the cylinder when the fuel oil is injected at the end of the compression stroke.

The pistons are water cooled, as also are the cylinders themselves when the engine has warmed to its work. To ensure certain ignition under running conditions, a steel plate is attached to the top of each piston in such

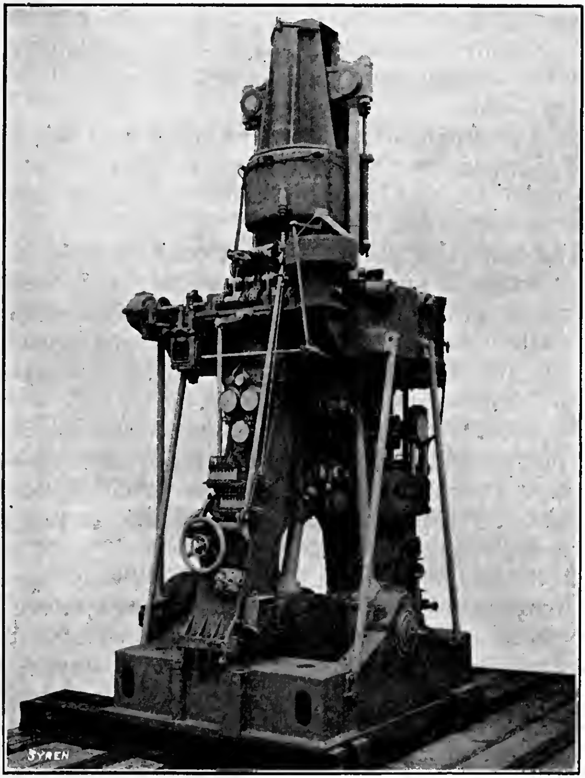


FIG. 23 *Wm. Doxford & Sons, Ltd.*

DOXFORD OPPOSED-PISTON OIL ENGINE

Single cylinder unit

a manner as not to be unduly cooled by contact with the piston proper.

Soon after starting up these plates become sufficiently hot to ignite the smallest charge of oil that is sprayed into the combustion space formed between the hot piston heads.

Fuel is supplied to the cylinders by solid injection, and there are two valves to each cylinder. They are placed at different levels and are spaced at an angle of 180° to each other.

The fuel valve mechanism is a good example of the high standard of excellence to which the process of accurately grinding cylindrical parts has been developed, especially when it is realized that there are no packed glands, and that the fuel is injected under a pressure of from 7,000 to 10,000 lb. per sq. in.

In the Doxford engine the low-pressure scavenge air pump is direct coupled to the main shaft, an independently driven compressor being installed for the supply of the pressure air necessary for starting and reversing the main engines.

In the Cammellaird-Fullagar engine the scavenge and high-pressure air compressors are directly driven by the main engines. Both of these engines have been very successful so far as they have been in service, and there is no doubt but that the opposed-piston type of two-stroke engine has a promising future before it for marine propulsion.

CHAPTER XV

FUEL OILS AND LUBRICATION

OIL fuel as a substitute for coal in the furnace of a steam boiler has attained considerable popularity for ship propulsion ; ease and cleanliness of storing and handling, the absolute control over the fire with a liquid fuel burner installation, together with other obvious advantages, serve to prolong the popularity of the marine steam engine or turbine.

Compared with the steam engine and its boiler, the oil engine takes up much less room. Bunker space is also reduced, the volume of 1 ton of oil is about 38 cub. ft., while 45 to 50 cub. ft. are necessary to store 1 ton of coal. Bulk for bulk, oil contains approximately 70 per cent more energy than coal, and coal must be stored in places that are easy of access, while oil may be stored in irregular shaped tanks, in the ship's bottom, or any space not otherwise useful.

Coaling ship is a crude operation, it takes a lot of time and requires a large staff of men ; in addition, the damage to paintwork and the work of cleaning up are items which must be taken into account.

Fuel oil may be taken on board through a hose pipe, thus oil-fired boilers benefit by these features of reduced bunker space and ease of bunkering.

The more economical use of oil fuel in an oil engine is, however, the chief factor which contributes to the reduction in bunker space when making a comparison with an oil-fired boiler.

A typical example of oil-fired boilers supplying steam to modern marine steam turbines may be cited in the

Canadian Pacific Steamships, Ltd., liner *Montcalm*. This vessel is fitted with turbine machinery of 13,000 h.p., driving the propeller shafts through double-reduction gearing.

On a 12-hour run the fuel consumption was ·984 lb. per shaft horse-power hour, which result, taking the calorific value of the oil fuel as only 18,000 B.Th.U. per lb., corresponds to an overall efficiency from fuel to shaft of about 14·4 per cent. The fuel consumption of a heavy oil engine of only moderate power may be taken as = ·42 lb. per b.h.p. hour, which figure, assuming the fuel to have a calorific value of 19,000 B.Th.U. per lb., gives an overall efficiency of nearly 32 per cent, and this is an average result for Diesel-engined ships.

Although a reduction in fuel cost of some 40 per cent may be realized by substituting the oil engine for the oil-fired boiler, the latter using an inferior and consequently cheaper fuel oil than the former, some marine oil engines are running on boiler fuel oil, thus further decreasing the fuel cost.

It is vital to the safety of a ship that its engines should run continuously when at sea, and until the successful use of boiler fuel oil as an engine fuel has been well established, its general use is not recommended.

The use of inferior fuel oils certainly entails more frequent attention to valves, etc., and is not likely to maintain the cylinders and pistons in the clean condition which is usual when engine fuel oil is used, and which conforms to the standard specification for such.

Boiler fuel oil has a comparatively high ash content, it is very viscous and of a sticky nature; altogether, it is filthy stuff, and as a consequence special arrangements must be made to ensure its clean and free passage through pipes, pumps, and fuel valves.

The National Fuel Oil Co., Ltd., give a rough guide

for discriminating between the two main types of fuel oil, the residual oil from what are termed paraffin-base crudes and suitable for Diesel and semi-Diesel engines, and the residual fuel oil from asphaltic-base oils suitable for steam raising and other industrial purposes.

The paraffin-base fuel oils are usually deep brown mobile liquids of a specific gravity, ranging from ·875 to ·910, which remain quite fluid at 32° Fah., while the asphalt-base oils are usually black in colour and range from ·910 to ·960 in specific gravity, and become highly viscous or semi-solid at 32° Fah.

Lubrication of Internal Combustion Engines. Efficient lubrication is an essential requirement with all internal-combustion engines, and because of its greater importance in this application than is perhaps the case with steam engines, closer attention is paid to the design and use of lubricators.

The forced-feed system of lubrication by means of mechanically operated sight-feed lubricators, is rapidly becoming standard practice on engines of all sizes.

On open type horizontal gas and oil engines, where a portion of the working surface of the piston is uncovered at the end of each stroke, the efficacy of the lubrication system is at once apparent, and the amount of lubricating oil supplied may thus be closely regulated.

The supply of oil to bearings and other parts is also well in view, and any undue heating of bearings is readily localized and further trouble prevented. The certain lubrication of engines having closed crank-cases, including large multi-cylinder vertical engines, where the piston, connecting rods, and intermediate shaft bearings are not accessible when the engine is running, is obviously a much more difficult job, and quite elaborate lubricating pumping sets are installed

for the purpose of giving a good supply of oil to these parts.

For the lubrication of marine engines the pumps are generally driven direct from the main engines, or they may be driven by an electric motor. In a well-designed plant the pipe service to each working part is easily traced, and relief valves, pressure gauges, flow indicators, etc., provided, so as to indicate immediately any fault in the system, such as oil filters becoming stopped, pipes choked, the supply to the pumps failing, or air locks occurring in the pipe system, etc.

The lubrication of air compressors requires special consideration and attention; in the case of "solid injection" engines a supply of air at a pressure of from 200 to 300 lb. per sq. in. is required for starting and reversing the main engines.

When the fuel supply to the cylinders is by "air injection" the delivery air pressure from the compressor is approximately 1,000 lb. per sq. in., and although in all cases the compressor cylinders are water cooled, and the pressure is raised from that of the atmosphere upwards in several stages, between each of which the air is further cooled, high temperatures are likely to occur in the system. Thus an unsuitable quality or quantity of lubricating oil may result in spring-controlled valves sticking and causing excessively high pressures to be generated, or the air compressor may act as an explosion engine with sometimes disastrous results.

In view of the importance of this question of lubrication, the following recommendations have been issued by the Diesel Engine Users' Association.

The lubricating oil used in the air compressor should be an oil of the highest grade obtainable, and must only be used in the smallest practicable quantity.

The following properties are necessary in all lubricating oils for Diesel engine compressors—

(*a*) The oil should be entirely free from suspended particles of water.

(*b*) The oil must be entirely free from sand or other inorganic material. No mechanical impurities must be visible in the oil when it is viewed by holding a sample in a glass vessel against a light.

(*c*) The oil must be entirely free from inorganic acids.

(*d*) Oils should not be lower in viscosity than 300 seconds Redwood at 70° Fah.; nor higher in viscosity than 3,000 seconds Redwood at 70° Fah.

(*e*) Oils should in no case be lower in closed flash point than 350° Fah.

(*f*) If the oil is to be used on an enclosed crank case high speed engine, in which the same lubricant is used both for the compressor and in the crank case, it should have a closed flash point of not less than 400° Fah.

For further guidance it may be pointed out that from past experience it has been found that the oils which have met with most success in Diesel engine air compressors, besides complying with the foregoing stipulations, have generally possessed properties lying within the following limits—

Specific gravity ·870 to ·915 at 15° C.

Viscosity (Redwood) 400 to 1,000 seconds at 70° Fah.
" " 75 to 125 " 140° "

Closed flash point, not less than 400° Fah.

Colour, red or yellow by transmitted light, but clear (not misty or smoky). Both straight mineral oils and compounded oils containing small quantities of saponified oil have met with success on Diesel engine compressor service, but the majority of successful oils have been straight mineral oils.

The consumption of lubricating oil, at say 4s. per

gallon, is an item of cost that has to be considered, and it is usually heavier with internal-combustion engines than with steam plants because of the greater importance of lubrication.

The quantity of lubricating oil used varies with the horse-power developed as well as with the rated horse-power of the engine.

In a paper on "Working Costs of Prime Movers,"* Mr. Oswald Wans gives a curve from which the lubricating oil consumption of a Diesel engine rated at 150 b.h.p. is seen to be = ·0083 pints per b.h.p. hour, and at a rated b.h.p. of 450 = ·0050 pints per b.h.p. hour. These figures correspond respectively to 2·0 per cent and 1·3 per cent of the consumption of oil fuel.

A marine Diesel solid injection engine of 2,500 b.h.p. using 10 tons of fuel oil per day consumes about 15 gallons of lubricating oil in the main engines. This corresponds to about 0·60 per cent of the quantity of fuel oil.

The lubricating oil consumption of semi-Diesel engines, such as are used for auxiliary work, has been found to be approximately 1½ per cent of their fuel oil consumption.

These figures for lubricating oil consumption are not, of course, to be rigidly applied, as so much depends on the system of lubrication adopted and on the care with which adjustments are made to provide for efficient and economical lubrication.

* Proceedings, I.Mech.E., October, 1917.

CHAPTER XVI

ENGINE REVERSING SYSTEMS

In the majority of installations on land, engines are enabled to work under conditions that, when compared with marine service, are practically ideal.

One need not here compare these conditions. It may, however, be well to point out that in addition to having to work under less favourable conditions the more exacting requirements of the marine as compared with the stationary engine comprise quick and certain running ahead or astern, and reliability of the engine to run in either direction, slow or fast, for long periods.

These requirements really form the most important part of the whole problem of the application of the internal-combustion engine to marine propulsion; economy in fuel consumption and bunker space, etc., being features of no value if the requirements mentioned are not realized in practice.

In vessels equipped with engines that are not directly reversible, and whose power does not exceed, say, 50 b.h.p., a propeller having reversing blades may be used; marine engineers will appreciate the limitations in connection with devices of this kind. Another method of reversing is through trains of wheels, and included in this system there are a number of designs. Wheel train gears cannot be used above certain powers owing to limitations of space in which to arrange wheels and brake drums of sufficiently large diameter.

In some applications the ahead clutch must have flexibility, that is it must be capable of slipping when desired as many engines will not run dead slow,

a necessary feature for manoeuvring in confined areas.

Further, the reversing mechanism must be so designed that it will stand the great stresses set up in cases of sudden reversal.

The arrangement of wheels in these gears has gone through practically all the possible combinations, as evidenced by an inspection of the many designs now in use. One of the most popular forms is the so-called epicyclic type, giving a reduced speed on the reverse.

This is an advantage, as it provides a greater torque to overcome both the inefficiency of running a propeller in the reverse direction and the increased resistance owing to the unsuitable shape of a boat for running astern.

In the design of these gears there are many limiting factors which " tie the hands " of the designer. In the first place the engine is placed low down in the boat, and this restricts the outside diameter of the wheel case and brake drums. Secondly, the gear must be capable of reversing the propeller shaft in the shortest possible space of time.

The gear must be free from internal friction when running ahead, and it should be of short overall dimensions so that the engine may be placed well astern. Wheel train gears must have a high margin of safety in toothed wheel brake and clutch construction, so as to provide for varying torque due to insufficient diameter of engine fly wheels. At the instant of explosion in four-stroke engines, the torque to which the gear is subjected may be anywhere between one-and-a-half to three times the average (depending on the number of cylinders) ; in engines of the constant pressure type the torque is more uniform.

In the design of epicyclic gears it must be remembered

that the brake drum has to hold against a force depending on the ratio of the number of teeth in the large and small wheels, the pinions being considered as levers with their fulcrums at the centre, the pressure on the pins will thus be twice the pressure on the teeth ; a further difficulty is the lubrication of the pinion pins. As the torque of the driven wheel is increased, there will be added to the brake retarding force a quantity depending on the ratio of the wheel diameters. The more nearly the wheels are made equal to each other in diameter the less will be the force to be retarded by the brake. The size of the pinions is, however, limited, as it is not advisable to have less than fifteen teeth in the smallest pinion.

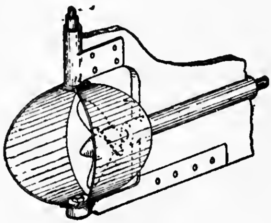


FIG. 24

THE KITCHEN REVERSING RUDDER

With the use of modern steels, and due to the high state of perfection to which wheel cutting has now been carried, there is no doubt but that suitable gears could be made for much higher powers than is current practice, but the difficulties encountered when suddenly reversing a heavy revolving mass would undoubtedly be serious, even neglecting the costly construction involved.

When the power to be transmitted is above say 100 b.h.p. at 100 r.p.m. or 400 b.h.p. at 400 r.p.m., the usual practice is to install a directly reversing engine.

An ingenious system of reversing the direction of a vessel by means of a special rudder has been developed and successfully applied to a number of small craft.

The Kitchen reversing rudder dispenses with the

need for either a reversing gear or a reversing engine, and while the engine may rotate continuously in the same direction, any gradation of boat speed or direction may be obtained, or the vessel brought to rest with the engine still running.

The reversing rudder system has already proved its suitability for vessels propelled by engines of a power usually fitted with wheel train reversing gears, and will no doubt be developed so as to dispense with the need for reversing engines in larger craft.

Marine and stationary engines above about 10 b.h.p. are started by admitting compressed air (in the case of low powered engines compressed products of combustion) into the main cylinder, and the direct reversal of large engines is also accomplished in the same manner.

For starting and reversing the lower powered semi-Diesel marine engines, a simple hand controlled non-return valve is fitted to the combustion chamber of the engine cylinder, and a pipe is led from this valve to a receiver, which is initially charged by means of a hand pump when the engine is first installed.

After the engine has been started up, the charging valve is opened slightly and a small portion of the cylinder contents passes into the receiver. As soon as the receiver pressure is sufficiently high, generally 100 to 200 lb. per sq. in., the valve is closed.

To start such an engine, after the preliminaries such as heating the cylinder head, priming, etc., have been attended to, the fly-wheel is rotated by hand until the crank of the starting cylinder is just over its top dead centre. On momentarily opening the starting valve the piston is pushed downward with sufficient force to carry the crank over the next inner dead centre position, when the fuel is injected and the engine commences

to work. The receiver is then charged to the necessary pressure for future use.

The larger multi-cylinder oil engines of the directly reversible type are fitted with starting air and fuel injection cams and operating gear, so that starting and reversing operations are carried out with the rapidity and certainty common to steam engines.

Compressed air is provided by compressors driven

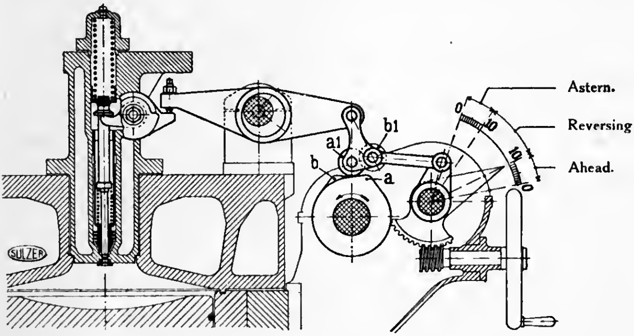


FIG. 25

FUEL VALVE OPERATING GEAR OF SULZER ENGINE

directly by the main engines, or separately by auxiliary power.

When the fuel supply to the cylinders is by air injection, the injection pressure is varied from about 550 to 1,000 lb. per sq. in., depending on the viscosity of the fuel oil and on the load against which the engine is working.

On some engines starting air is admitted to the cylinders at a pressure as high as the air injection pressure, i.e. up to 1,000 lb. per sq. in., but for marine purposes the starting air pressure with Diesel engines is usually from 300 to 400 lb. per sq. in.

When the starting air enters the cylinder at a high pressure and at atmospheric temperature, the subsequent expansion results in a much lower temperature than that of the atmosphere at the end of expansion.

Thus the cylinder metal is cooled to a lower temperature than when initial pressures of 300 to 400 lb. per sq. in. are used, and this contributes to sluggish starting.

With the lower initial pressures, the air supply to the cylinders is necessarily cut off at a later point in the piston stroke than when the higher initial air starting pressures are adopted, but the cylinder is not cooled to the same extent.

As a rule, when starting air is being admitted to the cylinder, the fuel valve is put out of action until the engine has commenced to rotate.

If the air starting and the fuel valve were allowed to open simultaneously, and the starting air pressure was approximately the same as the air blast or injection pressure, the fuel would not be effectively sprayed into the cylinder and violent pre-ignitions would result.

With the lower starting air pressure of some 300 lb. per sq. in., and a blast air pressure of 600 to 900 lb. per sq. in., the two valves may function together, but this is not general practice as it serves no useful purpose.

The elimination of high pressure air compressors and receivers will add to the popularity of the heavy oil engine for marine propulsion, and modern developments are certainly tending in this direction.

Air compressors and their accessories for pressures up to 300 lb. per sq. in. do not require such close attention or create such a feeling of what may be called nervous respect, as do compressors whose delivery pressures are in the neighbourhood of 1,000 lb. per sq. in.

Air receivers for the storage of low pressure starting air are necessarily of much larger volume than are high

pressure receivers, but less difficulty is experienced in keeping valves and pipe joints air tight, and there is less danger and anxiety as regards overheating of the system generally. The lubrication of low pressure air compressors does not call for such minute attention, and altogether, an engineer has greater confidence in power units whose working pressures are not much greater than those common to steam plants.

CHAPTER XVII

AUXILIARY MACHINERY

QUITE an important part of a marine installation is the auxiliary machinery. This includes steering gear, winches, electric lighting plant, ai· compressors, water service pumps, etc.

At the present time there are several systems in use for supplying power to the auxiliaries. The systems include : main engines, auxiliary oil and steam engines, electric motors, compressed air motors, and hydraulic transmission, which may or may not include an oil engine in its design.

How best to convey power to the deck machinery of an internal-combustion engined vessel is a problem of greater importance in some cases than in others.

For the smaller vessels and coasters that do not carry a sufficiently powerful electrical installation, the usual practice is to install deck winches that are gear driven through friction clutches from the shaft of a semi-Diesel engine.

These engines are generally of the single cylinder type, and may vary in size from 5 to 15 b.h.p., according to requirements.

Considering the very severe treatment and lack of attention that is usually the lot of deck machinery, it speaks well for the reliability of the internal-combustion engine that its combination with a deck winch is now a standard production.

One can hardly imagine a more difficult set of conditions for an internal-combustion engine to work under

than exist on, say, the deck of a trawler in a heavy sea.

Under circumstances such as then exist, the steam winch undoubtedly shows to advantage and gives a reliability of service, the value of which cannot be over-estimated.

On many of the larger internal-combustion engined vessels a steam boiler is carried for the purpose of steam heating, etc., and it is therefore not surprising to find that steam-driven deck winches and capstans are installed.

The steam engine is a self-starter in that it starts from rest against maximum load. The mean effective pressure in the cylinder may, at will, be nearly boiler pressure, and this pressure, when admitted to the cylinder, exerts a big torque at the crank-shaft and hence to the hauling chain or rope.

As the period of steam admission may be regulated to suit the load on the engine, it can thus be made to work economically all the time that circumstances will permit. An additional advantage possessed by the steam engine is that it is not likely to fail through the faulty adjustment of some small part of which the engine driver has no visible evidence.

An oil engine is not a self-starter in the same sense as a steam engine, the mean effective pressure in the cylinder will not exceed 100 lb. per sq. in., and this pressure is only usefully available when the engine is running at its normal speed and receiving the full charge of fuel. Then, again, as this pressure is only available during either one stroke in two or four, as against every stroke of the steam engine, in order that it may give a fairly uniform torque at the crank-shaft it becomes necessary to either increase the number of cylinders and fit a fly-wheel, or in the case of a single-cylinder engine, to fit a fly-wheel heavy enough to give uniform turning motion

and to prevent stalling the engine when the load is suddenly applied.

For operating air compressors, winches, and steering gears on the higher powered motor ships electricity is usually the motive power, this being generated by auxiliary oil engines located in the main engine room.

The motors used for deck work are of special design to stand rough usage, and are totally enclosed so as not to be affected by sea water, etc. They are connected to the winding drums by gearing and clutches in the usual way, and are provided with starting resistances, reversing switches, and the necessary interlocking gear and safety devices, so as to prevent misuse of the power by accident or ignorance on the part of the operator.

The combination of a constant speed electric motor driving a variable stroke plunger pump using oil as the working fluid has successfully solved the problem of operating the rudder of a motor ship.

In operation the system is very simple, and consists of a series of plunger pumps mounted so that the moving parts are balanced, the stroke of each plunger being simultaneously variable so as to deliver oil in quantity and at a pressure up to the maximum for which the pump is designed.

The pressure oil delivered by the pumps is conveyed through pipes to the two horizontal cylinders in which work the rams or plungers, which in turn give motion to the rudder arm and rudder. If the electric motor is working at full power and the pump plungers are working at their maximum stroke, the quantity of oil delivered will also be a maximum, while the delivery pressure will depend on the power of the electric motor.

When the pump plungers are working at a reduced stroke, the quantity of oil delivered will be less, the

delivery pressure depending, of course, on the opposing resistance.

In addition to providing a means whereby the rudder of a ship is made to respond to the actuating wheel in a manner not excelled by the best steam gears, the electric-hydraulic system is successfully employed for driving winches and capstans.

In this latter application, the oil from the variable stroke pump is delivered at a suitable pressure to the cylinders of what may be called a hydraulic motor, the shaft of which is connected to the winding gear.

By altering the pump stroke to suit the load on the winch rope, an ideal form of drive is obtained.

With this form of gear the electric motor runs continuously, all the operations of raising, lowering, etc., are simply and quickly carried out, and as the electric motor and pump may be placed in any convenient position away from the winch, they are thus protected from the effects of weather.

CHAPTER XVIII

THEORETICAL AND ACTUAL THERMAL EFFICIENCY

THE highest thermal efficiency of internal-combustion engines results when combustion takes place at constant volume. With Otto cycle gas and oil engines, where the compression pressure and temperature is kept low enough to avoid spontaneous ignition of the charge, the thermal efficiency is necessarily limited.

The thermal efficiency of the usual Diesel or constant pressure combustion engine, where the fuel is sprayed into the cylinder during a portion of the power stroke, is, for the same compression ratio, lower than with the constant volume cycle.

Although theoretically the thermal efficiency of an engine is highest when all the oil charge is instantly injected into the cylinder at the end of the compression stroke, the constant pressure cycle is preferred, as the pressure distribution in the cylinder more nearly approximates to steam engine conditions.

Consideration of the ideal or air standard thermal efficiency curve and experience with actual engines, has shown to what extent practice is justified in building engines carrying a higher compression pressure than is used in modern high compression heavy oil engines.

The best of these, having a volume ratio of compression of 15, i.e. $\frac{\text{total cylinder volume}}{\text{clearance volume}} = 15$ and a gauge compression pressure of 450 to 500 lb. per sq. in., give an indicated thermal efficiency of some 42 per cent, or about 65 per cent of that theoretically possible with the air standard cycle in which constant specific heat and adiabatic compression and expansion is assumed.

If the variable specific heat of the working fluid is considered, then the relative efficiency, i.e. $\frac{\text{indicated thermal efficiency}}{\text{ideal thermal efficiency}}$ is somewhat higher, with the same compression ratio.

Increasing the compression pressure with the object

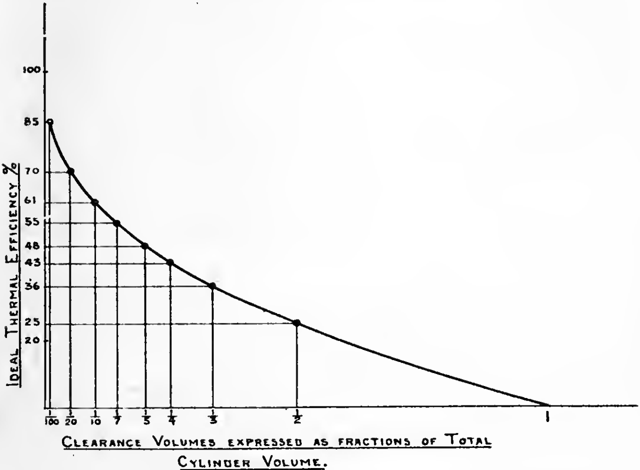


Fig. 26

AIR STANDARD THERMAL EFFICIENCY CURVE

Combustion at Constant Volume without heat loss to the cylinder

of obtaining a still higher thermal efficiency is, in practice, found not to be worth while, because at this part of the curve the pressure rises very rapidly for small increases in thermal efficiency, and the additional heat loss to the cylinder walls, as a consequence of the higher pressures and temperatures, largely negatives any gain that would appear to be theoretically obtainable.

With higher working pressures construction is more

difficult and costly, besides which the mechanical friction of piston and bearings is greater, as pistons require more rings, and the pressures on valves, cams, and shafts are greater. The greater importance of lubrication and cooling, and the increased inertia effects of the heavier reciprocating parts, are all points against the adoption of higher gas pressures.

In a Diesel engine, some 40 per cent of the total heat in the fuel supplied to it is utilized as work done on the piston, and this is the maximum that has been obtained from any standard type of internal-combustion engine. Neglecting the heat lost by radiation, etc., a good portion of the remaining 60 per cent of the heat energy is generally wasted in approximately equal proportions to the cooling water and through the exhaust valve to the atmosphere.

In factories and places where a supply of hot water or steam is required, and where large gas or oil engines are installed, waste heat boilers form a means of utilizing some proportion of the heat rejected by the engine.

During recent years, and after a vast amount of experimental work, a good deal of which has been carried out with praiseworthy thoroughness during a difficult period, Mr. W. J. Still, and those associated with him, have designed and built a number of engines which successfully convert into power much of the heat which is normally rejected by a Diesel oil engine.

In the Still system of construction, the engine is double acting ; one side of the piston may work on any combustion cycle while the other side functions as a single acting steam engine working under improved thermal conditions. A small boiler, together with a regenerator, is placed in series with the oil engine cylinder jackets, forming a closed circuit. Heat from the combustion end of the engine is thus given to the water in the jackets.

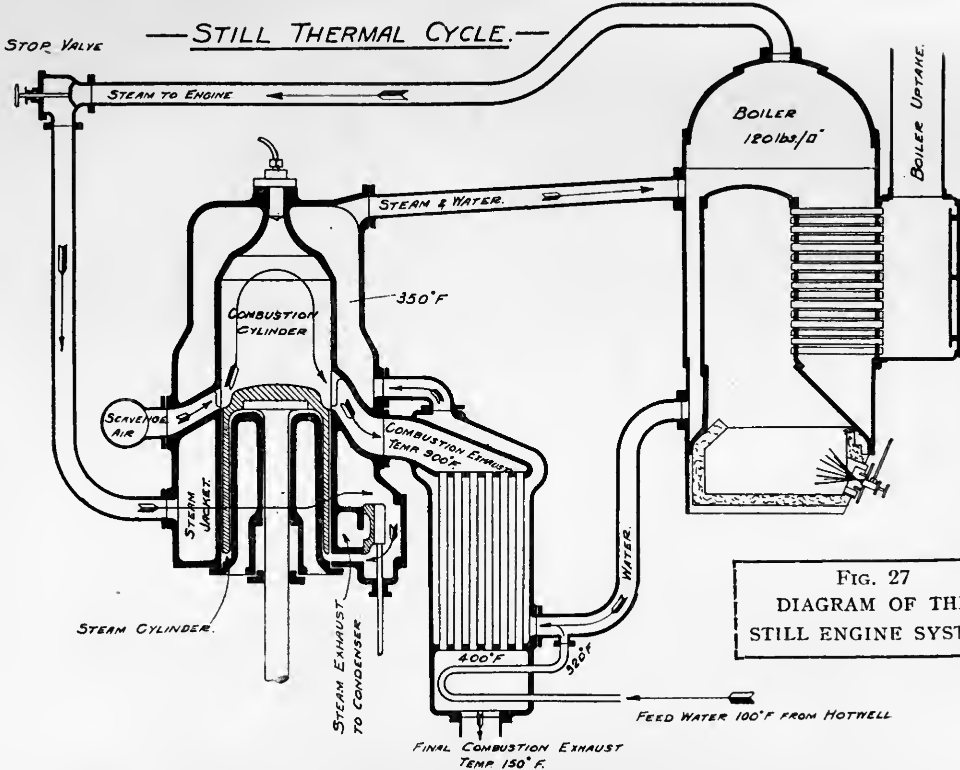


Fig. 27
DIAGRAM OF THE
STILL ENGINE SYSTEM

The exhaust gases flow through the tubes of the regenerator and thence to the atmosphere, giving up a large proportion of their heat to the water on the way. The engine is started, and for marine purposes reversed, by steam from the boiler, the latter being oil-fired for the purpose of raising steam from all cold. When the engine is running under load, the waste heat given to the boiler from the oil engine is sufficient to enable the burner heat to be dispensed with. As the jacket water temperature surrounding the cylinder is approximately 350°Fah. this enables a lower compression pressure, 300 lb. per sq. in., to be carried than is necessary in ordinary Diesel engine practice.

It is claimed that by utilizing the heat ordinarily wasted by a Diesel engine running under full load conditions, for the same fuel consumption, some 20 per cent increase in power is obtained by a Still engine.

With the Still system, air compressors and receivers are dispensed with, as the fuel supply to the oil engine end of the cylinders is by " solid injection."

CHAPTER XIX

TURBINES AND RECIPROCATING ENGINES

THE steam turbine has proved its superiority over the reciprocating steam engine, both as regards fuel efficiency and more even turning moment of the power-shaft, but the most important feature from a constructional point of view is the substitution of a rotating mass for the heavy reciprocating masses of the steam engine.

This latter feature has made possible the construction of units developing higher horse power, on a single shaft, than is practicable with steam engines of the reciprocating type.

Unfortunately, there is no exact information available relating to the construction and performance of experimental gas turbines built in this country, and as gas turbines are not yet a commercial proposition, a few remarks on the difficulties of the problem will suffice.

For a gas turbine to approach the fuel efficiency of a reciprocating internal-combustion engine, combustion must occur when the combustible mixture is under compression.

In a reciprocating engine compression is carried out in the engine cylinder, and not in a separate compressor. A compressor must, therefore, form part of any gas or oil turbine system, and if the compressor is of the reciprocating type, the advantages of a rotating power shaft in the turbine itself are largely discounted.

A separate air compressor, whether of the reciprocating or rotary type, is a source of power loss, the loss would, however, be reduced if some, if not all, of the power

required to drive it, is recovered by sending the hot gases from the turbine exhaust through a waste heat boiler.

In a gas turbine the combustible mixture is ignited electrically in chambers which are fitted with suitably-designed nozzles, and the high pressure gases, instead of pushing on a piston, are expanded in and discharged through the nozzles from which they issue at high velocity and temperature.

The issuing gases impinge on the blades of a turbine wheel, and so the kinetic, and not the pressure energy of the gases, gives rotary motion to the power shaft.

As the turbine blades will be subjected to the scrubbing and erosive effects of the high temperature products of combustion, the discovery of a suitable blade material and construction is not the least difficult part of the problem.

In a paper on "Large Internal-Combustion Engines,"[1] when referring to the turbine gas engine, Professor Watkinson says—

"If it were possible to combine the high thermal efficiency of the present type of internal-combustion engine with the great mechanical advantages of the turbine, an ideal motor for most purposes would be available."

"The greatest difficulty is due to the high exhaust pressure, the pressure of the atmosphere. With steam turbines the exhaust pressure is about one-fifteenth of atmospheric pressure, and the success of the steam turbine is mainly due to the comparative ease with which this low exhaust pressure can be attained." "The steam turbine can usefully expand the steam to 1 lb. absolute,

[1] "Proceedings of the Liverpool Engineering Society," April, 1909.

and with an initial pressure of steam of 182 lb. per sq. in. absolute, the pressure ratio of expansion is $\frac{182}{1} = 182$. If the turbine worked non-condensing, the initial pressure would require to be $14{\cdot}7 \times 182 = 2675{\cdot}4$ lb. per sq. in. to give the same ratio of expansion."

"With the internal-combustion turbine it would be difficult to arrange for the exhaust pressure to be much below atmospheric pressure, and therefore a very high initial pressure would be required to secure high efficiency."

Experimental turbines using power gas and oil fuel were constructed in Germany by Holzwarth in 1908, and an illustrated account of the latest turbine of the Holzwarth type is given in the *Motor Ship* for January, 1921. This is a horizontal machine which is said to develop 500 b.h.p. at a speed of 3,000 r.p.m., and is stated to be a commercial proposition.

It is interesting to note, however, that marine oil engines have not yet been built to develop as much horse power, on a single shaft, as reciprocating steam engines. This is a problem which is being investigated by engineers all over the world, and hence the delay in attacking the internal-combustion turbine problem.

Marine steam engines with five cylinders coupled to a three-throw crank-shaft are at work developing 15,000 i.h.p., while the highest power at present obtainable commercially from a single-piston four-stroke marine Diesel engine is approximately 400 h.p. per cylinder. With eight four-stroke cylinders arranged in line, and this is the maximum number coupled to any single shaft, the total i.h.p. is 3,200.

Engines of the two-stroke cycle opposed-piston type develop as much as 750 i.h.p. per cylinder, but as each cylinder is fitted with two pistons having the same

diameter and stroke, this figure is not exceptional. The maximum total power so far developed by a set of four-cylinder opposed-piston engines is 3,000 i.h.p. at a speed of 77 r.p.m., and this corresponds to a shaft horse power of 2,700.

Two-stroke single-acting engines developing 650 i.h.p. per cylinder are built with six cylinders in line, the total shaft horse power developed at 100 r.p.m. being 2,700.

Prior to the war, experiments were being made both in this country and abroad with high-power single-cylinder oil engines.

In a paper before the Institution of Civil Engineers (1921 Conference), Mr. J. Richardson pointed out that, in numbers, 96 per cent, and in tonnage 88 per cent, of the world's shipping requires less than 5,500 i.h.p. of machinery per ship, and thus comes within the scope of the oil engine so far as horse power is concerned.

At the same conference, Sir James McKechnie, of Vickers, Ltd., gave some test results that were obtained in 1913 from a two-stroke Vickers engine. This single-cylinder unit had a bore of 30 in., the piston stroke being 36 in. At a speed of 140 r.p.m., 1,056 b.h.p. was developed, and on a full power trial extending over a period of 30 hours the fuel consumption was ·4061 lb. per b.h.p. hour.

CHAPTER XX

THE CASE FOR INTERNAL COMBUSTION

THE popularity of the steam engine is largely due to its so-called simplicity and to its undoubted reliability of working, often under anything but favourable conditions.

For these reasons, and due to the fact that high-powered steam units have been developed, which, being generally in the care of skilled attendants, give a good fuel economy, the development of the internal-combustion engine, for high powers at any rate, has not in the past received the encouragement it deserves.

Simplicity of construction is no longer accepted as a guarantee of reliability, and while an internal-combustion engine is not necessarily more complicated than is a steam engine, by reason of its unfamiliar appearance to the more numerous users of steam engines it is generally looked on as such.

With ordinary observation and care, a fairly skilled fireman has no difficulty in maintaining a boiler efficiency of 70 per cent ; unless the boiler is of poor design.

But with all the skill he is able to put into the job of stoking a boiler whose efficiency may be so high as 80 per cent, his steam plant cannot convert more than 20 per cent of the heat in the coal stoked, into the useful work of driving machinery.

This 20 per cent is a maximum efficiency figure that can only be obtained from highly efficient boiler plants supplying steam to high-powered steam turbines, fitted with all the customary contrivances for reducing steam waste ; the whole plant being run under expert supervision. With reciprocating steam engines of the

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best class the fuel efficiency does not exceed 16 per cent.

There are thousands of steam engines at work which do not make use of more than 5 per cent of the heat in the coal stoked to the boiler, and it is certain that the fuel efficiency of the average steam engine does not exceed 10 per cent.

A gas engine easily converts from 20 to 25 per cent of the heat in the coal stoked to its gas producer into work available at its crank-shaft for driving machinery, while a further 20 to 30 per cent is available for steam raising or water heating, by sending the exhaust gases through the tubes of suitable designed waste heat boilers and by feeding the boiler with hot water from the cylinder jackets.

A " heavy oil " engine will give out as useful work at its crank-shaft as much as 32 per cent of the energy in the fuel oil supplied to it.

By concentrating on the production of heavy oil engines for marine propulsion, engineering firms throughout the world are now building engines that for the same power developed consume less than one-half of the quantity of oil burned in the furnaces of an oil-fired boiler.

For 100 years steam was the only practicable form of heat engine, and to date its length of service is approximately 150 years.

During this period our knowledge relating to combustion has increased, and as the question of fuel economy becomes of greater importance, the future of the internal-combustion engine, combining as it does the essential features of high fuel economy with reliability of working, and the many valuable features, such as convenience and space economy, already alluded to, is assured.

The successful management of an internal-combustion engine installation does call for higher manipulative skill and a keener sense of the correct adjustment of valves, bearings, etc., by the engineer in charge, than does a steam plant.

In the case of oil engines, a sound technical knowledge of the character and properties of liquid fuels is necessary.

Realizing the importance of the marine oil engine, the Board of Trade now conduct examinations for engineers desirous of obtaining an oil engineer's certificate in the various grades.

The rules laid down as regards training are such that anyone obtaining the certificate may, with confidence, be given charge of any internal-combustion engine installation.

Misconception sometimes arises regarding the use of electricity for power purposes. Power is required to generate electricity, and the dynamo or generator must be driven by steam or internal-combustion engines, or by wind or water power. Electricity is used to transmit energy, and thus it will be understood that an electric dynamo or motor is not a prime mover.

It is up-to-date practice, where a number of machine tools or separate process machines are installed in workshop or factory, to drive each machine by its own electric motor in preference to having a cumbersome and inefficient transmission system of shafting, pulleys, and belts.

Winches, cranes, lifts, pumps, fans, etc., are often driven by electric motors, where for reasons of situation, convenience, etc., a heat engine of any kind could not be installed. Whether or not in applications such as these it would be more economical for individual firms to generate their own electricity by using gas or oil engines,

or to take current from the public supply companies, depends on the horse power required and the convenience of the situation. Used in conjunction with both steam and internal-combustion engines, electricity serves a useful purpose, and as an economical power transmitter for stationary and traction purposes, it is largely indispensable.

In concluding this treatise on the development of internal-combustion engines, the many different types and features of construction that have been considered may seem to convey the idea that the internal-combustion engine is in a somewhat undeveloped state, but this is not the case at all.

Improvement in detail, if not in principle, will necessarily continue, whilst changes in the types of engines may be made owing to new developments and discoveries in the field of fuel production.

The present satisfactory state of development to which internal-combustion engines have attained, is due in no small degree to those who work in the more complex fields of thermodynamics and chemistry.

The more abstract work of the investigator does not attract the attention of the average user of a power plant His interest is, perhaps naturally, only awakened when a finished product in the way of a cheap power producer is announced to the world.

Research work of the kind that is experimental or mathematical, or, as is generally the case, a combination of the two, is of fundamental importance and great value. As a rule, such work involves financial loss to the investigator, and is often additional to exacting professional duties. It is to the credit of the scientists of this and every other country that so much valuable data is obtained and freely published to the world.

That the value of the results obtained is appreciated

and made use of by manufacturers and engineers generally, is evident by the animated discussions that take place when the results of investigations are presented at the meetings of our scientific and technical institutions.

Experimental work in connection with internal-combustion engines is necessarily of a costly nature, even when confined to the improvement of detail parts. As an example, it may be mentioned that oil-spraying devices have been the subject of experiment since the first oil engine was built, and still are an attractive detail for experiment. Not that modern spray devices are unsatisfactory, but experiments are being made rather with the object of simplifying construction, and rendering cleaning less frequently necessary when running for long periods with inferior fuel oils.

Much work of an experimental nature is being carried out on the construction of high-power marine engines with the object of reducing the number of cylinders and cranks, and such work can only be undertaken by firms who have had long experience in the construction of internal-combustion engines, and who have a trained staff of designers, as well as workshops equipped with the best machine tools procurable.

As regards the extended use of internal-combustion engines, it will be realized that a steam engine has a long life, whether doing duty as a stationary engine or as a marine engine for the propulsion of ships, and it is not to be expected that existing steam plants will be scrapped and gas or oil engines substituted. For all new power requirements, and when the replacement of worn-out and under-powered steam engines is being considered, the claims of a suitable type of internal-combustion engine cannot be overlooked.

Every type has been thoroughly tested, and as modern gas and oil engine builders keep a complete record of

tests of fuel consumption, horse power developed, endurance, etc., of every engine turned out, having confidence in the dependability of present-day materials and the perfection of their manufacturing processes, they are thus able to guarantee a high standard of service and one easily maintained.

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